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Urban runoff quality in the river Sowe catchment

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Urban Runoff Quality in the River Sowe Catchment

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Abstract

There have been no previous studies carried out on the impact of urban runoff in the Coventry City centre area. The culverted nature of the River Sherbourne, and many of its tributaries, makes the investigation of intermittent pollution and rainfall events expensive and impractical, when using traditional spot sample methods. Storm events have been monitored over a period of over 60 months upstream and downstream of the City, using continuous water quality monitors and auto-spot sample methods. The receiving waters of the River Avon had previously suffered annual fish mortalities as a result of summer storm events causing oxygen depletion. Previous studies (Clifforde and Williams 1997) on the impact of Coventry Sewage Treatment Works effluent on the watercourse, have suggested a major component of the intermittent pollutant load arising from the City (upstream of the Sewage Treatment Works), which requires evaluation and remediation.

This research identifies the contaminants found during a series of storm events impacting on the River Sherbourne culvert, and discusses the relationship between them and the increased flow measured. The methodology was divided into 3 Phases; Phase 1 examined all of the watercourses in the River Sowe catchment, and identified the culverted streams and drainage system giving an indication of the presence of pollutant sources. Continuous monitors were deployed within the four identified drainage systems to pinpoint intermittent and illegal contaminated discharges, and these discharges were subsequently redirected to the foul sewer or stopped. Phase 2 examined the quality of the River Sherbourne culvert upstream and downstream of the city centre, and demonstrated (using continuous monitors and automated sampling), that six combined sewer overflows discharging to the watercourse upstream of the culvert were operating unsatisfactorily. The dissolved oxygen levels were

significantly reduced during rainfall events (with a loss of diurnal variation), and total ammonium levels exceeded current water quality standards. The results were used to instigate a remediation scheme to replace the overflows with additional foul sewerage capacity, and a single high-level storm relief.

Phase 3 examined the impact of urban runoff during rainfall events after the improvements made following Phases 1 and 2. The results suggest a marked improvement in the water quality, with little impact from organic pollutants. Dissolved oxygen concentrations remained high during many of the post-remedial rainfall events, and ammonia levels remained largely insignificant. The results indicated a fall in pH levels during the rainfall events and increases in all of the heavy metals analysed, though not beyond current water quality guidelines.

The efficiency of using continuous monitoring in Coventry was assessed and likely sources of the contaminants in urban runoff were considered. The statistics of compliance with percentile standards do not allow for short-term pollution or storm events, which may kill all aquatic life whilst not breaching water quality standards. Using continuous monitors to identify intermittent and illegal discharges in underground drainage systems was an efficient and cost-effective method of reducing the impact of urban runoff in a failing watercourse. The methodology can be applied to other urban areas to identify unidentified illegal and intermittent point sources.

Routine monthly monitoring of an urban watercourse may not identify the peaks and troughs associated with rainfall events that may breach toxicological guidelines, and will not identify intermittent and unknown pollutant sources; particularly when discharging outside of normal working hours.

This research was a unique and comprehensive investigation into the nature and composition of urban runoff in the City of Coventry, and local data gathered will be

invaluable in promoting further research, improving local knowledge of the urban environment in preparation for the Water Framework Directive (2000/60/EC), and in planning for environmental improvements in the future.

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For my Father, Leonard Andrew Hyde, who died 12 days after this thesis was submitted for examination.

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Chapter 1. An introduction to anthropogenic pollution sources and an investigation into urban runoff problems in an inner city environment.

Introduction

Water covers approximately 75 percent of the World's surface with a volume of over one billion cubic kilometres. Only a small part (0.003%) of this volume is fresh and accessible however (Smol, 2002), with 97% of the total comprising the oceans, with the majority of the remaining 3% being frozen in ice caps and glaciers, or buried deep underground (Mason, 2002). For most of the Earth's history, only natural elements such as wind, ice and water, along with geological events and tectonic movements, have effected gradual (and occasionally catastrophic) transformations of the environment, with micro-organisms, plants and animals acting reciprocally within the biosphere. No geological event in a billion years, including the formation of mountains or the occurrence of periodic glacial ages, has posed a threat to terrestrial life comparable to that of human overpopulation and intervention. About 5×10^6 years ago the first hominid species evolved, and as knowledge has progressed, and science and technology have developed, Mankind has not only been able to identify the processes and consequences of environmental change, it has also developed the means of drastically altering the environment through habitat loss, urban expansion, exploitation of natural resources and the introduction of pollutants from agriculture, industry and urbanisation (Mannion, 1997). In particular most environmentalists now accept global warming caused by human activities as fact, and if the use of fossil energy is not controlled in the short term, the effect on natural resources, including water, will be severe. The human population, currently estimated at 6.24 billion, is predicted to rise to 10 billion by 2050, and approximately 80% of the global population today live in developing countries where already, some 25000 children die

each day from a lack of safe drinking water and basic sanitation (Mason, 2002). The populations of most underdeveloped countries are doubling every 20-25 years (Ehrlich *et al*, 1972) and some 40 percent of the world's population in over 80 countries are affected by serious water shortages, whilst in other countries water is too expensive to recover or treat to an acceptable standard. Pollution therefore is a gross misuse of an essential resource, and it is only in recent years that the problem has been addressed seriously (Sections 1.2 and 2.2.3).

This chapter identifies that increased pollution is associated with population growth and urbanisation, and recognises that as the population increases, the pollution generated by affluent and developing countries can impact on the global environment by climate change. Recent acknowledgement of anthropogenic global environmental impact from world leaders has led to pressure on developed countries to reduce emissions from industrial processing, and the European Community is leading by example in setting tough standards to reduce emissions (and therefore impact) to the local and global environment. These targets are set in Europe as Directives, which in turn are implemented in the UK as Regulations to control process emissions and determine environmental standards, including water quality standards. These water quality standards are used to identify whether urban runoff is impacting on the River Sowe catchment and whether identification and remediation of pollutant sources can be achieved by meeting the aims and objectives identified in Section 1.5.

1.1 Urbanisation

The rate of growth of population in the twentieth century has been accompanied by settlement of virtually all the inhabitable parts of the world and an increase of more than a billion people in urban settlements of over 20000 inhabitants. Urbanisation has led to a quadrupling of energy consumption and considerable usage of depletable

resources (Ward and Dubos, 1974). Extractive and processing plant machinery, as well as waste production, have created localised industrial landscapes and can also be responsible for altering environmental quality at a distance, through air and water pollution (Mannion, 1997). The production of wastes by these communities has led to the development of treatment and disposal methods, including biological treatment, incineration and land-filling that will still give rise to pollution of land, air and water. Legislation to identify permissible pollution levels may demonstrate intent to maintain national economic competitiveness, rather than protect the local or global environment, and it is not surprising that policy makers and planners from countries seeking economic development are not side-tracked by environmental concerns (Ward and Dubos, 1974).

1.2 Climate change

The plan of action agreed by the leaders of the G8 at Gleneagles in July 2005, identified for the first time, (with the agreement of all present) that climate change is happening now, and that human activity is contributing to it. The summit acknowledged that emissions globally should 'slow, peak and then decline' and that further progress was expected in the UN Climate Change conference in Montreal in November 2005 (www.G8.gov.uk). The Kyoto Protocol, signed in 1997, requires 35 industrialised countries, including the U.K., to reduce greenhouse gas emissions to approximately 8% below the 1990 levels by the years 2008-2012, but Australia and the United States (www.usembassy.it/pdf/other/RL30692.pdf) have refused to ratify the treaty. The alternative 'G6' Asia-Pacific climate change programme agreed by Australia, America, China, India, Japan and South Korea in July 2005, focuses more on developing new 'cleaner' technologies rather than cutting greenhouse emissions, and has been described by some environmental groups (Friends of the Earth included) as 'nothing more than a trade

agreement' (www.foe.uk). On a global scale, economic competition is still a higher priority amongst some of the larger developed countries, and some, (e.g., USA), are strongly opposed to any reduction in emissions that may harm their manufacturing capability or their ability to compete with developing countries. The European Union has recently identified that it is seeking legally binding global restrictions on greenhouse emissions, with calls for global emissions cuts of 20- 40% by 2020 on 1990 figures (Decision No. 1600/2002/EC). The Sixth Environment Action Programme of the European Community published in September 2001 identifies Climate Change as a priority issue, along with Nature and Biodiversity; Environment and Health and quality of life; and Natural Resources and Waste; though the resultant 2002 Climate change programme has been more successful in some European countries than others, with Luxembourg cutting its emmissions by 44% on 1990 figures and Ireland increasing emissions in 2001 (2003 figures) by 31.1%. The Commission estimates that in the longer term a 70% reduction in global greenhouse gas emission, compared to 1990 will be required. The European Community has produced a wealth of legislation to protect water quality in the European Union, including the Water Framework Directive (2000/60/EC) which will take a holistic approach to environmental quality risk management and form a part of the Sixth Environment Action Plan to manage risks from chemicals (including pesticides). Other legislation allied to this cause include the following:

- Nitrates Directive (91/676/EEC) - identification of Nitrate Vulnerable Zones to control nitrate pollution from diffuse sources
- Urban Wastewater Treatment Directive (91/271/EEC) – to control urban & certain Industrial wastewaters, including treatment standards and nutrient removal
- Discharge of Dangerous Substances Directive (76/464/EEC) – prevention (List I) and control (List II) of emissions at source of identifed substances
- Bathing Water Quality Directive (76/160/EEC) – identifies standards, including bacteriological for bathing waters (coastal and inland)
- Groundwater Directive (80/68/EC) – prevents and controls List I & II discharges to groundwater resources, including disposal of spent agrochemicals

1.3 Pollution and water quality monitoring in the United Kingdom

In England, Wales and Northern Ireland, European legislation becomes law in the form of Regulations and all of the Directives listed in Section 1.1 have now been implemented or are in the process of implementation, to improve water quality in this country. The Water Framework Directive has translated into The Water Environment (Water Framework Directive) (England and Wales) regulations 2003, and is a wide ranging overhaul of water quality control which identifies pollution risks, ranging from diffuse nutrient pollution, urban runoff and chemical and biological quality, to more holistic considerations such as biodiversity, alien species, anthropogenic influences (such as flood defence structures) and abstraction pressures. The regime will introduce a requirement for extensive monitoring and a programme of measures for each river basin (or individual catchment or water body) to address and review the identified risks every 10 years, in order to meet a required standard (not yet set) for each parameter of 'good environmental quality'. Monitoring of watercourses in England and Wales is currently carried out by the Environment Agency (Scottish Environment Protection Agency in Scotland), in the form of the General Quality Assessment (GQA) as discussed in Section 2.4. The Agency has identified the following trends (EA Water Quality report, 2003):

- **Biological quality - an indicator of overall 'health' of rivers**
  In 2003, 95% of rivers were of good or fair quality, compared with 90% in 1990. In 2003 some 4% of rivers were poor and less than 1% were bad. In 2003, 70% of rivers were of good quality. This is a slight improvement on 2002. (Indicator: River biology). Between 1990 and 2003, some 31% of rivers (net) improved in biological quality. Most of this improvement occurred in the first five years and the improvement since then has been more gradual. In some places, for example in Wales, biological quality has deteriorated since 1995.
- **Chemical quality - an indicator of organic pollution in general**
  Over 94% of rivers were of good or fair quality in 2003, compared with 85% in 1990. In 2003 over 5% of rivers were poor and less than 1% were bad. In 2003, 65% of rivers were of good quality, a small decrease from 2002. (Indicator: River chemistry). Overall, some 37% of rivers improved (net) between 1990 and 2003. Improvement has now levelled off and there has been a very slight decline since 2000. Over the last three years there has been a decline in quality in Southern Region. This is due to issues with using new field meters, which have now been resolved.
  Nutrient status - phosphate and nitrate in rivers
  In 2003, 53% of rivers had high concentrations of phosphate (greater than 0.1mg/l), compared with 64% in 1990 (Indicator: River phosphate). In 2003, 27% of rivers had high concentrations of nitrate (greater than 30mg/l), compared with 32% in 2000 and 30% in 1995 (Indicator: River nitrate).

- **Aesthetic quality of selected rivers**
  A selection of sites was surveyed in 2000 that people visit frequently. About two-thirds of 452 sites were aesthetically good or fair quality and the rest were poor or bad.

In summary there has been an improvement in water quality in UK rivers since 1990 with a slight decline in some areas in the past 3 years. Despite this, sampling budgets are reduced periodically to meet reduced Grant in Aid funding, and permissive sampling (i.e. taking samples which are not related to enforcement or compliance monitoring) has all but disappeared in some areas, unless linked to emergency incidents. The number of parameters monitored is slowly being reduced to meet the requirements for monitoring any upstream Consent to Discharge issued under the Water Resources Act, 1991, or to report (as part of national water quality reporting programmes) the progress in meeting UK legal obligations to the European Community. GQA monitoring currently calls for all chemistry sampling sites to be sampled 12 times per annum (Environment Agency, 1997) regardless of local uses or objectives and any additional sampling for operational purposes has to be justified according to local priorities. This research aims to address the problem of identifying intermittent pollution sources that may not be identified by routine GQA monitoring, using continuous monitoring in urban drainage systems. The process systematically traces intermittent sources for remediation, with the resultant improvement in water quality achieved with substantial savings over traditional permissive sampling investigations. The methodology can be transferred to any major conurbation affected by urban runoff and non-visible illegal or intermittent discharges.

1.4 Hypotheses.

The aims and objectives of this study into urban runoff problems, with particular emphasis on urban drainage in the City of Coventry, arise from the following initial hypotheses:

A) That occasional spot sampling of the urban watercourses does not give an accurate assessment of the chemical water quality and that the use of biological sampling does not address the issue of identifying intermittent discharges in an inner City environment with culverted watercourses and streams. Furthermore that the use of continuous monitors can give an accurate graphical representation of the changeable nature of quality and flows in urban watercourses and assist in the investigation and removal of polluting intermittent organic discharges in a cost effective manner.

B) That analysis of phosphate concentration will reveal that combined sewer overflow (point) sources in an urban area, contribute to the high level of phosphate per capita discharged to receiving watercourses.

C) That analysis of water quality during storm events at multiple sites on a continuous basis will reveal hitherto unknown cross connections between surface and foul sewers, broken sewers and industrial and commercial effluents quickly, and that removal of these illegal discharges will result in a marked improvement in water quality, as identified by routine sampling programmes, for affected watercourses.

1.5 Aims and Objectives of this research

1) To investigate the nature and impact of storm water runoff (specifically from the City of Coventry in the River Sherbourne and River Sowe catchments), and identify the sewerage systems which can contribute to a marked deterioration in receiving waters following storm events. To assess the dry weather pollution load and determine if the River Avon will still fail toxicologically based fundamental intermittent standards (Crabtree et al 1995) if no action is taken, for oxygen and ammonia concentrations regardless of effluent input from Coventry and Rugby Sewage Treatment Plants.

2) To investigate the use of multiple probe continuous monitors in urban surface water drainage systems and culverted watercourses, and determine whether this method can be cost-effective in identifying urban runoff problems arising from urban runoff, combined sewer overflows and industrial operations.

3) To investigate if the identification and removal of point source pollution will change the impact of urban drainage on receiving watercourses, by analysis of a number of storm events monitored upstream and downstream of the City.

4) To determine the optimum frequency for sampling or assessing water quality in an urban environment.

5) To identify potential pollution problems remaining in urban runoff in the River Sherbourne catchment and consider the implications, if any, for potential future use of the watercourse (in terms of recreation, amenity or abstraction), and appropriate water quality standards.

1.6 Areas of Research

This research will identify some potential sources of pollution and the chemical and biological impacts of pollution on receiving watercourses, by reference to published literature worldwide (Chapter 2), and also historical data collected by the Environment Agency and its predecessors locally in the area studied (Chapter 3). The research will build on an investigation into stormwater quality downstream of a major sewage works as part of an Urban Pollution Management study (Section 2.5) to determine potential intermittent and illegal pollutant sources contributing to a deterioration of a major urban drainage system during wet weather (Section 3.6). To determine every possible pollution source in a major City in the United Kingdom is impossible, but this study will determine whether the use of continuous monitors could be an efficient means of identifying below ground sources in a major surface water drainage network and make the task manageable

and worthwhile without having to spend millions of pounds in the process. The Water Framework Directive (2000/60/EC) identifies urban runoff as an indicator of environmental quality that will eventually have to be addressed for specific waterbodies to achieve good environmental status (Sections 2.6 and 3.11). This has been addressed to some extent in Coventry as a result of this study, by the use of continuous monitors to identify pollution problems associated with urban runoff and intermittent diffuse sources.

The River Sowe catchment was identified for this research because it is a mixture of open and culverted drainage systems which serves all of the drainage from one major City (Coventry) before discharging into the Warwickshire Avon, which is not only used for recreation and amenity, but forms the focus for tourism-based activity at a number of historic towns such as Warwick, Stratford upon Avon, Evesham and Gloucester (Section 3.1). The receiving watercourse was also subject to annual deoxygenation during the summer months following storm events with dissolved oxygen saturation (DO) levels falling to near zero, resulting in the death of several thousand coarse fish at a time (Section 3.6). Public pressure on improving the water quality of the River Avon and its tributaries led to the Coventry Urban Pollution Management study (Section 3.7) which investigated the impact of treated and storm sewage flows from the only major sewage works serving the City of Coventry, (Coventry (Finham) Sewage treatment Works), discharging over 90 mega litres per day of treated sewage (plus storm flows) to the lower reaches of the River Sowe catchment (Figure 3.1). The River Sowe is therefore a self-contained river catchment serving only one major conurbation, with an extensive surface water sewerage system and known foul sewage overflows, draining to a popular watercourse showing signs of deterioration and with regular fish mortality requiring emergency re-aeration response every summer. These factors made it an ideal area for investigation into urban runoff and this became significantly important when the Urban

Pollution Management study identified that drainage from the city itself was a major contributor to the deoxygenation problem (Section 3.8).

1.7 General methodology

The investigation into suspected pollution problems in the City were divided into 3 phases as detailed in Section 4.2 and below:

Phase 1:

The examination of the impact of unidentified sources of contaminants entering the extensive surface water system and culverted streams that would potentially impact on the River Sowe and River Sherbourne. The early monitoring runs identified which rivers and surface water sewers demonstrated a potential pollution problem and progressed to an intensive study of the potential sources of contaminants to elicit their removal or remediation, as detailed in Section 4.3.1. This phase would identify for remediation, contamination sources impacting between monitoring points on the River Sherbourne culvert upstream and downstream of the city centre as identified in Phase 2 and 3.

Phase 2:

Determination of the impact of six known combined sewer overflows located at Albany Road that discharged to the River Sherbourne directly above the culverted Section. The Albany Road overflows were not monitored directly due to Health and Safety considerations, but the effects of their operation were determined on the River Sherbourne at locations situated above and below the consented outfall at Hope Street. The initial investigations were used to present a case to the Severn Trent Water for removal or remediation of the storm overflows, based on gathered evidence of unsatisfactory operation in the form of continuous monitoring data (Chapter 5).

Phase 3:

Following the subsequent removal of the six unsatisfactory overflows from 2) above (Section 4.5), and the introduction of a new foul sewer with only one high level storm relief overflow (Chapter 6), the identification of any resultant improvements in the quality of the River Sherbourne to investigate remaining urban runoff pollutants.

The River Sowe (which is predominantly open along its length) was found to be relatively clean, with no identified intermittent pollutant source other than the culverted Hall Brook, which was subsequently studied as part of Phase 1. The River Sherbourne was extensively monitored as it is open above and below the city, with a culverted stretch within the inner ring road of the city (Section 4.4); it received the effluent from six combined sewer overflows that were suspected by the National Rivers Authority to be operating unsatisfactorily. The river received urban runoff directly from the city centre road network and pedestrianised shopping areas (Figure 2.2), plus industrial and residential surface drainage from an extensive system of culverted watercourses and surface water drainage systems, as shown in Figures 3.2 and 4.5.

Chapters 5, 6 and 7 identify the results of data collection for Phases 1, 2 and 3 respectively, and Chapter 8 gives a summary in relation to the objectives outlined above, and identifies a model for the River Sherbourne, with suggestions for future research.

1.8 Conclusions

This chapter has outlined the hypotheses in relation to the investigation and improvement of urban runoff environmental impact and stated the aims and objectives to be achieved by this study. The Coventry drainage area has presented a number of problems relating to diffuse pollution sources (Section 2.1.1), and urban runoff, which can be identified in cities across the world (Section 2.2), and the methodology for

researching these problems (Section 4.2) could therefore be applied elsewhere; not only to increase the already extensive wealth of literature on urban runoff, but also to identify and address some of the hidden intermittent pollutant sources, and bring about an improvement in water quality. This methodology could be used to investigate urban runoff as part of a programme of measures to improve urban water bodies, and bring them into good ecological status for the Water Framework Directive (2000/60/EC), as discussed in Section 2.6.

The next chapter embeds the objectives of this research in a review of literature identifying the nature and sources of urban runoff, and the contribution and effects of local and global airborne and water borne pollutants impacting on an urban watercourse.

Chapter 2. Literature Review

Introduction

The fact that rivers become polluted as a result of urbanisation has been known for some time (Klein, 1962). The impacts of water quality deterioration on human health, destruction of natural habitat and biodiversity, and in reducing the volume of usable water are visible in many parts of the world. The projected spread of major cities and rapid industrialisation in many parts of the world can only make the problem worse if measures are not taken in time to adequately deal with waste treatment and pollution control in urban areas. Identification of the problem is key to identifying treatment and control measures required (Abu-Zeid *et al.*, 1998). This Chapter will review literature sources to investigate the types and sources of pollution in urban environments (Section 2.1 and 2.2), the potential impact on water quality and ecology (2.3), and the current methods of assessment for chemical and biological quality of watercourses in England and Wales (Section 2.4).

2.1 Types and sources of pollution

2.1.1 Sources of Pollution

Pollution sources can generally be categorised into two types: point source and non-point source (Choe *et al*, 2002). Point source refers to the polluted effluent from a specific point or an extremely small area of land. Examples of point sources are domestic or industrial wastewaters, and the route and quantity of such pollution sources, when identified, are easily measured or controlled in open watercourses. Current practice in the UK is to build separate foul and surface water sewerage systems, so that harmful sewage discharges to watercourses would be reduced (Luker and Montague, CIRIA report 142, 1994). However, pollution from misconnections, illegal discharges

and storm overflows is still a common cause of pollution incidents reported in urban watercourses (Environment Agency, 2003).

In the River Sherbourne catchment (Figure 3.2), most of the drains and culverted streams feeding the watercourse are underground and are therefore hidden. Point sources therefore become non-point sources in effect, and identification of specific urban drainage problem sources such as unknown foul sewer overflows or intermittent polluting discharges is required. Non-point sources can arise when it rains and the pollutant is discharged from a wide area so that it cannot be considered to be a point source (Choe *et al.,* 2000). As the treatment facilities of point sources expand and water quality improvements are identified, the relative importance of the treatment of non-point sources is increasing. However it is difficult to establish a proper process to control non-point sources because the source and the route of effluent are uncertain and the concentration of pollutants released to the environment can be high when it rains (Choe *et al.,* 2000). Hypothesis A (Section 1.4) suggests that the use of continuous monitors can reduce the size of the potential problem area, and reveal previously unidentified impacts as point sources, allowing further investigation and removal, or redirection of pollutants to treatment facilities. Urban non-point source pollution is a significant contributor to water quality degradation (Brezonik& Stadelmann, 2002), and non-point sources resulting from rainfall not only contain a variety of pollutants, but may also carry a large pollutant load so that they exert a great influence on receiving waters (Whipple and Hunter, 1981; Characklis and Weisner, 1997). Sources of this type of pollution include precipitation, soil erosion, accumulation and wash off of atmospheric dust and street dirt, fertilisers, pesticides and direct discharge of pollutants into storm sewers (Novotny & Olem, 1994). Generally, the polluting nature of storm

runoff using discrete sampling has been well studied, with many reports detailing the potential cocktail of contaminants present (Ellis 1989; Deletic 1997; Choe *et al.,* 2002).

2.1.2 Ecological Impacts

The ecological impacts of urban runoff have been described as physical, chemical or a combination of both (Borchardt and Sperling 1997), and much of the work has concentrated on highway drainage (Perdikaki and Mason, 1999; Sansalone and Buchberger 1997; Robien *et al* 1997; Butler and Clark 1995; Luker and Montague 1994), Combined Sewer Overflows (Lee *et al.,* 2000; Grum *et al* 1997;), sediment transport and treatment (Mc Neill *et al.,* 1998; Lee *et al.,* 2004; Laxen and Harrison, 1977) or the presence (or absence) of the so-called first flush effect (Saget *et al.*,1995; Lee and Bang, 2000; Forster, 1996; Harrison and Wilson, 1985). Watershed planners and environmentalists need to be able to estimate non-point source loads to lakes and streams if they are to plan effective management strategies (Brezonik, & Stadelmann, 2002). This information will include data on single storm events as well as seasonal trends, and will consider site-specific drainage components such as Combined Sewer Overflows (CSOs), Separated Sewer Overflows (SSOs), as identified in this investigation (Chapters 5 and 6), and land use in the area of study. Non-point pollution arising from stormwater runoff has been identified as one of the major causes of deterioration in the quality of receiving watercourses, and the characteristics of urban runoff are more difficult to quantify than those of wastewater (Field *et al.,* 1982; Novotny and Olem, 1994; Bang *et al.,* 1997; Lee and Bang, 2000). The degraded character of urban streams results not from one single factor, but from the interaction of a variety of detrimental effects, although Extence (1978) found that inert sediments are the main cause of poor biological quality (Section 2.4.2) in receiving watercourses. Sartor *et al* (1974) identified that the Internal Federal Water Pollution Control

Administration (1969) emphasised a need for more definitive investigations as to the source, cause and extent of urban pollutants, the interrelationships and significance of the variables, and the development of standard procedures for measuring street surface contaminants (IFWPCA, 1969). Their work, covering 12 cities in the United states, came to the conclusion that runoff from street surfaces is highly contaminated and that the contaminant varied widely according to rainfall intensity, surface properties, particle size, antecedent dry periods and the efficiency with which streets were cleaned (Sartor *et al.,* 1974). Harremoës, (1981) suggested 3 areas to be considered to counter the effects of urban runoff; control at source, improved street cleansing and treatment of runoff. The author anticipated that further controls at source would not be possible without further knowledge of the pollution effects of specific compounds.

Multi-faceted investigations are becoming increasingly important in the United Kingdom with the proposed re-classification of all European watercourses for the implementation of the Water Framework Directive (2000/60/EC). The proposed classification process for defined water bodies within a river basin or catchment will not only rely on chemical and biological assessment but also on other perceived risks to the river basin, such as morphological change, nutrients, pesticides, alien species and urban runoff as discussed in Section 2.6.

2.1.3 Modelling Water Quality

As a result of the requirement for a holistic approach to non-point pollution, many water quality prediction models have been assessed over the years (Ayherre *et al* 1998; Dempsey *et al* 1997). Due to the impacts on receiving waters, and the expense involved in obtaining monitoring data on non-point source pollution, interest has grown in compiling and analysing existing data to develop predictive models for urban stormwater loads and concentrations. Such models can help planners and engineers

make loading estimates for unmonitored catchments. However the increasing cost of maintaining sustainable urban drainage installations, including contaminated sediment removal, (possibly as special waste in some areas), suggests that local data, site specific conditions, and targeted removal of contaminants still have a part to play in allocation of finite resources. There has been a degree of criticism (Lee and Jones-Lee, 1993) of the Environment Protection Agency in the US, for the implementation of a blanket set of environmental quality standards (following amendments to the Clean Water Act), based on worst-case or near worst-case exposures to available forms of contaminants, for controlling stormwater discharges (US EPA, 1990; EPA, 1992). As a result of this there have been a number of studies to identify critical source areas whereby potential problem sites are identified within an area so that Best Management Practices, including the use of detention ponds and Sustainable Drainage Systems (SuDS), can be targeted to serve specific problems at a lower cost of construction and maintenance (Bannerman *et* al., 1993; Lee and Jones-Lee, 1993). Perdikaki and Mason, (1999) suggested that where treatment of flows prior to sedimentation is not possible, future efforts should concentrate on limiting pollutants generated at source. In the United Kingdom a recognition of the need to assess actual pollution problems using toxicological data and short term exposure limits such as Fundamental Intermittent Standards, (see Section 2.5.1) has led to the development of the Urban Pollution Management (UPM) procedure which was used to investigate the impact of Coventry (Finham) Sewage Treatment Works on the River Avon catchment, (Section 3.7) and also was used as the basis for the investigation work carried out during this study on the River Sherbourne catchment.

Estimates of urban stormwater pollutant loads are required to assess the impact of stormwater pollution on urban watercourses and to design methods for minimising their impacts (Lee and Bang, 2000). Brezonik and Stadelmann (2002) examined relationships

between runoff variables, and the characteristics of storms and watersheds, to determine runoff volumes, loads and resultant event-mean concentrations (EMCs). Typically, the concentration of pollutant in surface runoff is presented as an Event Mean concentration (EMC) due to the large fluctuation of pollutant concentrations during a rainfall event. EMC is defined as the pollutant load divided by the total runoff volume and is represented as:

$$EMC\ (mg\ l^{-1}) = \frac{\Sigma Qi\ Ci\ \text{(total load)}}{\Sigma Qi\ \text{(total runoff volume)}} \quad \text{.....Equation 1}$$

(Where Qi = water volume (l) and Ci = concentration of pollutant mg l^{-1}.)

The most accurate models for EMCs were found when sites were grouped according to common land use and size. Lee and Bang (2000) employed this method to compare run off from different land uses as discussed in Section 2.2.1.

When EMCs and runoff volume are available, normalised total mass of pollutants per event can be calculated as follows (Lee *et al.* 2004);

$$\text{Normalised mass for storm event} = \frac{\text{EMC X total runoff volume}}{\text{total mass for season}} \quad \text{.....Equation 2}$$

From this a graph of cumulative pollutant load against cumulative runoff volume can be made which can be used to determine whether the actual load monitored during a storm event exceeds the expected level or not. A positive result indicates the presence of a first flush effect (Saget *et al.*,1995; Sansalone and Buchberger, 1997).

This sort of data summary and analysis was carried out on a coarse scale for the United States (EPA, 1983, Driver & Tasker 1990) and on a finer scale for several metropolitan areas and sites in them (Brezonik & Stadelmann, 2002). The EPA (1983) reported that the effects of urban runoff on receiving water quality are highly site specific, making it difficult to predict impacts, and design appropriate management and control practices,

without site-specific data for a particular catchment (EPA, 1983). Brezonik and Stadelmann (2002) also concluded that variability from one location to another and from storm to storm indicates the need for local data. Urban runoff quality can be influenced by specific point discharges unknown to the investigator and the drainage system is sometimes, as in the case of Coventry drainage, composed of culverted streams and an extensive network of piped connections. A 'general' knowledge of the composition and 'likely' sources of urban runoff does not assist in the identification and remediation of major runoff related problems, as in the River Sowe catchments, and their often catastrophic effects on the receiving watercourses (see Section 3.6). The use of 'off the shelf' water quality modelling packages for an urban catchment (such as the River Sherbourne), where there are probably numerous unknown illegal discharges, and the probability of many uncharted Combined Sewer Overflows (CSOs) and Separate Sewer Overflows (SSOs), would be extremely difficult, and could lead to misleading conclusions relating to predicted pollution levels. This was demonstrated in the case of the Earlsdon Area Drainage Study, which led to the introduction and design of the six unsatisfactory CSOs at Albany Road, Coventry (see Section 3.5). Conversely, the water quality model employed in the Coventry (Finham) STW UPM study (Clifforde & Williams, 1997) gained valuable site specific data from spot sampling and continuous monitoring of the open watercourses and effluent streams during a number of storm events (Section 3.7).

Although extensive urban runoff modelling began in the 1980s, routine monitoring of urban runoff discharges is still in its early stages of development, and little consistency or comparability has been achieved among monitoring programmes (Leecaster *et al.*, 2002). In the 1980s and early 1990s, Severn Trent Water Authority and the National Rivers Authority carried out regular monitoring of all public surface water sewers in the

Coventry area with outfalls to watercourse in excess of 300mm. This routine spot sampling of urban surface water would be considered too expensive and time consuming now as a method of pollution control, with Environment Agency analysis costs (2006) for river suite analysis (sanitary determinands) of £35.00 and heavy metal (toxic six) analysis of £12.50 per sample, and with limited resources available for monitoring non-permitted (and therefore non-chargeable) discharges. Automatic sampling equipment has to be set prior to storm events and resultant samples removed, which can prove heavy work requiring two or three people. Monitoring between storms is not cost effective, as automatic sampling equipment has to be cleaned, maintained and refilled, and manual sampling incurs costs for transport, salary, training and analysis. Much of the previous work reviewed to date (Lee and Bang, 2000; Brezonik and Stadelmann (2002); Herrmann *et al,* 1994; Characklis and Weisner, 1997; Namdeo *et al.,* 1999; Hares and Ward, 1999) has used discrete sampling on a limited number of storm events, whereby samples have been taken at regular intervals from identified locations during the duration of a storm. Currently in the UK there is no regional or national assessment of the environmental deterioration caused by road runoff discharged to ground and surface waters (Shutes *et al,* 1999). The Research carried out for this thesis suggests that the regular use of continuous monitors can provide a reliable and cost-effective tool to determine actual run off quality and variance from an urban area such as Coventry, into an urban watercourse, such as the River Sherbourne culvert. This will be important in considering suitable improvement measures for enhancement of the watercourses identified as 'at risk' (see Section 2.6) under the Water Framework Directive (2000/60/EC). The technology can also identify, and facilitate the removal of, unknown, illegal or unsatisfactory consented storm overflows and misconnected industrial and domestic pollutant sources, in otherwise relatively inaccessible drainage systems such as

the culverted brooks and extensive surface water systems found in the River Sowe, and more specifically, the River Sherbourne catchment areas.

2.2 Potential Contaminants arising from Urban Runoff

2.2.1 Soils and land-use.

Pollution of rivers may occur as a result of natural run off from land, carrying silt, manure and vegetable matter into the watercourse on an intermittent basis. Urban stormwater runoff significantly increases sediment and nutrient loadings to surface waters (Brezonik, & Stadelmann, 2002). Coarse particles will not be carried in suspension even in fast river flows, but are transported by rolling along the riverbed by the process of saltation (Luker and Montague, 1994). The extent and character of this pollution depends on the chemical and physical characteristics of the riverbed and land-use in the catchment area (Klein 1962). Borchardt and Sperling (1997) developed the idea that general land-use and natural physical characteristics were key factors in determining pollution levels in considering the combined effects of physical and chemical factors, following urbanisation, on environmental impact. They found that acute ecological damage could occur on three counts, due to hydraulic (physical) factors, chemical processes (Section 2.3.1), or a combination of both. Hydraulic disturbance of river ecosystems occurs when bed shear stress exceeds frequencies and levels of natural conditions, and may result in catastrophic drift of benthic communities (From Bartlett, 1979). The type of urban land-use plays an important role in determining the environmental impact of urbanisation; commercial and industrial areas contribute more pollutants than open space, parks and low-density residential land uses (Mulcahy, 1990), and surface runoff from residential areas and industrial estates is likely to contain hazardous materials (Choe *et al*, 2002) as discussed further in Section 2.2.3 below. In a study examining urban runoff in the Twin Cities Metropolitan Area of Minnesota,

(TCMA), Brezonik and Stadelmann (2002) found that pollutant loadings in urban areas occurred all year round, but the highest loadings were identified during the summer, particularly following long antecedent dry periods, and catchments with even a few construction sites were found to be especially large sources of solids and nutrients (Section 2.2.3). A previous study of the northern TCMA catchment by Arntson and Tornes (1985) found that the most urbanised areas had the highest concentration of metals, chloride, dissolved solids and suspended sediment. Rural sites had low concentrations of metals but the highest concentrations of many nutrients, with Total Phosphate concentrations comparable at rural and urban sites. Urban runoff may contain relatively large particles such as pebbles and gravels, which are transported with some of the smaller particles such as sand and silt (Laws, 1993). The majority of the transported sediment in a stream consists of smaller particles such as sand, silt and clay, which can remain suspended in the water column as suspended solids. Fine particles may only settle out of suspension as a result of natural coagulation, or after long periods of low-energy flow (Luker and Montague, 1994). In some cases a significant amount of biological materials, such as leaf litter, may also be present. Excrement and urine deposited on roads and pavements can be a significant source of bacteria, viruses, and soluble and particulate organic contaminants (Muschack, 1990) with high oxygen demands (Section 2.3.1). Dead animals will also contribute to the organic and bacterial contaminants discharged into the drainage systems.

In studies in Cincinnati, Ohio in the United States (Laws, 1993), relative sanitary concentrations for solids, COD, BOD and nutrients were determined as given in Table 2.1.

Table 2.1. Reasonable COD, BOD, total N and total P values for urban runoff, raw sewage and rainfall (from Laws, 1993).

Material (mg l^{-1})	Urban Runoff	Raw Sewage	Rainfall
Suspended Solids	227	200	13
Chemical Oxygen Demand (COD)	111	350	16
Biochemical Oxygen Demand (BOD)	17	200	No data
Total N	3.1	40	1.3
Total PO_4 (as P)	0.36	10	0.08

The results suggest that Suspended Solids and BOD may be much higher in runoff than in some treated sewage, for example Coventry treated sewage effluent, which has imposed consent limits, (rarely exceeded), of 15 mg l^{-1} BOD, 20 mg l^{-1} Suspended Solids and 3 mg l^{-1} Ammonium (as N). Hvitved-Jacobsen *et al.* (1986), identified that 99% of Total P and 85-90% of nitrogen nutrient loadings in runoff can be removed in the sediment, with provision of effective treatment (settlement) facilities. Another American study in Wisconsin (Bannerman *et al.*, 1993) studied the impact of various land uses by sampling runoff from a variety of surfaces using specially implanted sampling cans in lawns, parking areas, highways and roofed areas. Using simulated rainfall volumes and mean concentration values, (often from combining different samples as composites for the same land use), they determined that streets were a critical source of pollutants for every land use, and that most of the solids runoff comes from industrial parking areas. Industrial roofing proved most critical for Total Zn concentration and lawned areas were identified as critical sources for phosphates. Pollutant values for the different land uses were summarised in Table 2.2.

Table 2.2 – Geometric mean Concentrations of Contaminants in runoff from source areas and storm sewer outfalls (adapted from Bannerman *et al.*, 1993)

Contaminant	Collector streets	Lawns	Driveways	Roofs	Parking lots	SWS Outfall
Residential Source Areas						
Total Solids (mg l^{-1})	**493**	600	306	91	NI	369
Suspended Solids (mg l^{-1})	326	397	173	27	NI	262
Total P (mg l^{-1})	1.07	2.67	1.16	0.15	NI	0.66
Total Cd (µg l^{-1})	1.4	-	0.5	-	NI	0.4
Total Cr (µg l^{-1})	12	-	2	-	NI	5
Total Cu (µg l^{-1})	56	13	17	15	NI	16
Dissolved Cu (µg l^{-1})	24	6	9	10	NI	5
Total Pb (µg l^{-1})	55	-	17	21	NI	32
Total Zn (µg l^{-1})	339	59	107	149	NI	203
Commercial Source Areas						
Total Solids (mg l^{-1})	Values	NI	NI	112	127	Values
Suspended Solids (mg l^{-1})	Shared ↑	NI	NI	15	58	Shared ↑
Total P (mg l^{-1})	with	NI	NI	0.2	0.19	with
Total Cd (µg l^{-1})	residential	NI	NI	-	0.6	residential
Total Cr (µg l^{-1})		NI	NI	-	5	
Total Cu (µg l^{-1})		NI	NI	9	15	
Dissolved Cu (µg l^{-1})		NI	NI	6	9	
Total Pb (µg l^{-1})		NI	NI	9	22	
Total Zn (µg l^{-1})		NI	NI	330	178	
Industrial Source Areas						
Total Solids (mg l^{-1})	958	Values	NI	78	531	267
Suspended Solids (mg l^{-1})	763	Shared ↑	NI	41	312	146
Total P (mg l^{-1})	1.5	With	NI	0.11	0.39	0.34
Total Cd (µg l^{-1})	3.3	commercial	NI	-	1	1
Total Cr (µg l^{-1})	15		NI	-	12	6
Total Cu (µg l^{-1})	76		NI	6	41	28
Dissolved Cu (µg l^{-1})	18		NI	-	15	10
Total Pb (µg l^{-1})	86		NI	8	38	25
Total Zn (µg l^{-1})	479		NI	1155	304	265
(Key: NI = not in land use)						

In a study assessing land use and characterisation of urban stormwater runoff in Korea, Lee *et al.* (2000), sampled 34 storm events at nine sites with different land uses (residential and industrial), giving a set of ranges for event mean concentrations, as shown in Table 2.3.

Table 2.3 Event Mean Concentration Values from a study of residential and industrial areas in Korea (from Lee and Bang, 2000)

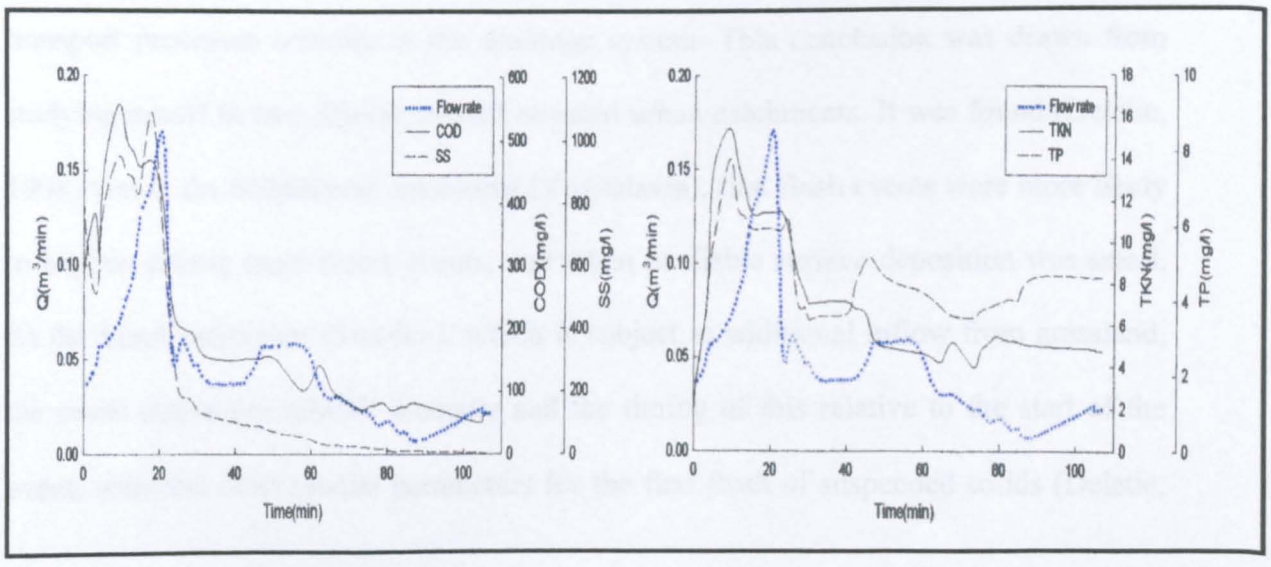
Parameter	Residential Areas		Industrial Areas	
	minimum	maximum	minimum	maximum
BOD	12	254	No data	6324
COD	21	1455	10	810
Suspended Solids	13	2796	3	530
Nitrates	0.01	35.2	0.01	5.43
Phosphates (total)	2.4	22.4	0.1	10.1
Pb	0.002	0.89	0.004	0.891
Iron	0.1	22.9	no data	no data
All values in mg l^{-1}				

They found that the relative magnitude of pollutant loadings from high to low was:

high density residential> low density residential> industrial> undeveloped watershed

Choe *et al.*, (2002) also found that the concentrations of such pollutants are related to the land use, the type of catchment and the rainfall conditions, and that surface runoff generated in residential and industrial zones in urban areas, is highly likely to contain hazardous materials. They identified that the concentrations of most pollutants in surface runoff increased with increased runoff flow rate at an early stage of rainfall and that peak pollutant concentrations were reached prior to peak runoff flowrate at most sampling sites. Their results are shown in fig 2.1.

Figure 2.1; Typical characteristics of urban runoff in a study of residential single family zone 22/11/99 (adapted from Choe *et al.*, 2002)



This phenomenon is reported to be more important when the watershed is small (less than 100 hectares) and contains mostly impervious surfaces (Lee and Bang, 2000) and is explained by the fact that the local surface runoff of the pollutant stored on the road surface or in the drainage system precedes the main runoff flow. Two peaks of suspended sediments may be observed, as the detritus lodged in the drainage system is removed first, followed by material from the road surface itself (Luker and Montague, 1994).

Using 4 datasets collected over two wet seasons in California, Lee *et al.,* (2004) found that the concentrations of pollutants were up to 20 times higher at the start of the wet season compared to later investigations, and that mass emissions rates were similarly increased. There is however an alternate view (Deletic, 1998; Saget *et al.,* 1995; Lee *et al.,* 2004) that because of the even distribution of street dusts, and the continued washoff of the sediment throughout a storm event, a first flush effect is not always demonstrated when sampling road runoff. Indeed the scale of the first flush effect (or the duration of data collection attributed to this phenomenon) is, in itself, a matter for discussion. Deletic (1998) considered that any strong first flush effect at the end of a piped system was not likely to be caused by a first flush of pollutant to the system from the surrounding area, but rather, that it may be caused by pollutant transformations and transport processes actually in the drainage system. This conclusion was drawn from studying runoff in two similar asphalt covered urban catchments. It was found (Deletic, 1998) that at the Miljakovac catchment (Yugoslavia), first flush events were more likely to happen during large storm events, and when available surface deposition was small. At the Lund catchment (Sweden), which is subject to additional inflow from grassland, the event maximum rainfall intensity and the timing of this relative to the start of the event, were the most crucial parameters for the first flush of suspended solids (Deletic,

1998). Deletic (1998) went further to suggest that the first flush effect may be site specific and complex, and that it could not be calculated or modelled with a universal set of climate, rainfall and runoff characteristics. Bellinger *et al.,* (1982) reported that the first flush effect was a function of variables, such as the pattern of rainfall, the travel time and the distribution of solid material over the catchment. Novotny and Olem (1994) identified that the extent and nature of watercourse pollution during wet weather is related to technical control measures such as storage, Combined Sewer overflows and separators in urban drainage systems. This effect is important in considering the results obtained from the use of continuous monitors to identify intermittent or storm related discharges in the culverted watercourses and surface water sewers of Coventry (see Chapter 5).

Lee *et al.,* (2004), found very little rain during the summer in California (other than rare tropical storms) and evidence of seasonal first flush during the winter/ spring seasons. Results for TOC, Specific Conductivity, Zn and Total Suspended solids were approximately 5.5, 4, 2.5 and 1.5 times higher respectively during the first part of the wet season following the long antecedent period, than at the end. The length of the antecedent dry period is significant for different contaminants in different ways; Soluble pollutants deposited by traffic (Section 2.2.3) or atmospheric fallout (Section 2.2.2) will collect approximately in relation to the length of time since the last rainfall event. Those contaminants deposited by irregular events, such as spillages, and road salt distribution, may, or may not, form a major component of first flush runoff (Luker and Montague, 1994). Insoluble and adsorbed materials (Section 2.2.3i) may collect until there is a storm of sufficient intensity to remove them (Harrison and Wilson, 1985), and the antecedent period may refer to the period since the last rainfall of sufficient intensity to remove them (Luker and Montague, 1994).

Lee *et al.*, (2004) found that in the results of a study by Los Angeles County Department of Public works (www.ladpw.org/wmd/NPDES/report_directory.cfm), using data from 24 events over 2 wet seasons, the concentrations measured for total heavy metals were higher than basic water quality sanitary determinands, and that results for Total Cu, Total Al and Total Zn were 22, 18 and 13 times higher at the start of the wet season, gradually decreasing with further monitoring during winter and spring. In all they found less than 10% of the rainfall gave rise to the greatest concentrations of pollutants and that the concentration of pollutants measured during the first storm of the wet season was 4.6 times greater than the concentrations measured for the last storm of the season. Saget *et al.*, 1995 suggested that first flush is defined as occurring when at least 80% of the pollutant load is delivered in the first 30% of runoff volume. Strecker *et al.*, (1990) suggest that the first 10% of the total discharge will be more highly polluted than the remaining 90% of runoff. Others suggest 25% runoff volume (Vorreiter and Hickey, 1994) or conclude that if a mass cumulative curve is plotted for an event that exceeds the cumulative runoff volume curve; a first flush effect has been demonstrated (Sansalone and Buchberger, 1997). In a study analysing 117 events from 7 combined sewers in France, Saget *et al.* (1995) concluded that the first flush did not exist, as the strict definition used in the study was not met during the monitoring period, whereas Gupta and Saul (1996) concluded that a first flush effect regularly occurs in many combined systems. It would appear that the local conditions greatly influence the likelihood, size and longevity of a first flush effect, where present, and that the measurement programme employed can easily influence the results if storm events are missed or not represented adequately by the collected samples. One possible reason for inconsistency of the results could be the poor quality of data. In both cases cited, data collection during one event was not frequent enough to correctly monitor short, intense

summer storms, which can last only 20 minutes yet be so intense that they include some very polluted water (Deletic, 1998). Early flows may have been missed, particularly if sampling was triggered by flow regimes. The short duration, high intensity type of rainfall event typical of the UK in summer is probably the most detrimental form of storm with respect to pollution levels, because of the abrasive nature of the high intensity rain, and the limited volume of water that falls. A high percentage of pollutants are mobilised very quickly forming a concentrated effluent at the start of the rainfall event (Luker and Montague, 1994). This was demonstrated in the results of monitoring Coventry rainfall events during Phases 1, 2 and 3, as discussed in Chapters 5, 6 and 7.

Klein (1979) studied 27 watersheds to determine the relationship between stream quality and the extent of urbanisation. Using biological data as an indicator of water quality, it was identified that deterioration in an urban watercourse was dependant on the level of imperviousness in the surrounding area. The first evidence of impact from urban runoff was present at more than 12% imperviousness, but did not become severe until greater than 30%. Stream quality impairment could be therefore prevented if imperviousness was kept at below 15%, and that for more sensitive streams imperviousness should not exceed 10%. The Urban Design Study of 1999 (Coventry, 1999) identifies that the area draining to the Urban River Sherbourne catchment is above 50% within the ring road boundary of the city centre (Figure 3.7) and the results of the routine biological monitoring carried out by the Environment Agency at Charterhouse, as shown in Table 3.1 reflect this theory, with poor results identified. Part of the impact on the River Sherbourne may be due to the fact that as imperviousness increases, the base flow arising from groundwater sources generally decreases (Klein, 1979). A recent reduction in the use of groundwater abstraction sources by industry in the city, may counter this deficit.

2.2.2 Air Pollution

Airborne particulate matter is one of the most obvious forms of atmospheric pollution, whether it comes from a chimney or diesel exhaust pipe (Quality of Urban Air Group, 1993). Rainwater can add its own adsorbed and dissolved pollutants to the loads generated by other sources, particularly by scavenging particulate matter (Zinder *et al.*, 1988; Luker and Montague, 1994). The airborne or settled contaminants particles can be transported to watercourses following precipitation, as discussed below. Lead in the atmosphere is present in particulate form, as are other metals such as Cd, Ni and Cr. Many organic compounds such as polynuclear aromatic hydrocarbons and dioxins are also found as airborne particles. From a public health perspective, these particles are controlled to prevent harm to human health as they can irritate the eyes, nose and throat, whilst smaller particulates can penetrate the lungs, obstructing air sacs and becoming absorbed into the blood stream (NSCA, 1999). In terms of air quality and health, the following pollutants are considered important by DEFRA as identified in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (HMSO, 2000): Nitrogen and sulphur compounds, carbon monoxide, particulate matter, oxidants, metals and organic compounds, such as Benzene and 1,3-Butadiene. All of these chemicals can be considered potential sources for street dusts (Figure 2.2), as they may become available to local drainage systems by deposition or from being washed out by precipitation. They are therefore potential sources of pollution in urban drainage systems, which may be detected in analysis of water quality or sediments. Coventry has a centrally located incinerator plant, with emissions controlled under the Pollution Prevention and Control (England and Wales) Regulations (2000 SI 2000/1973), as required by the Integrated Pollution Prevention and Control Directive (IPPC 96/61/EC). This may impact directly on the composition of street dusts (Section 2.2.3), and the quality of urban runoff from

street surfaces in the city. Recent results for emissions from this plant are given in Chapter 3.

Air particles arise in 3 forms or modes (Quality of Urban Air Group, 1993):

a) Nucleation Mode	These particles are < 0.2μm in diameter and are transient in that they form larger particles. They arise from combustion processes such as from incinerators smelters etc
b) Accumulation Mode	These particles are 0.2 – 2μm in diameter and are formed by coagulation of nucleation mode or condensation of vapours. They are the most stable and long-lived matter lasting 7 – 30 days in the atmosphere. They are not efficiently removed by gravitational settling, scavenging by rain, or any other mechanism.
c) Coarse Mode	These are the largest particles (>2μm diameter), and are formed by mechanical attrition (e.g. soil dust, industrial dusts and sea spray). They have high settling speeds and therefore spend only a short time in the atmosphere before deposition onto roofs, roads and paved areas. These contaminants are easily transported to the surface water sewerage system and the receiving watercourses.

It is generally the smaller Nucleation Mode particles (<0.2μm), produced during high temperature combustion, that pass through emission controls and escape to the atmosphere, their small size allowing maximum transport from the source. Coagulation of these fine particles, or condensation of vapours, gives rise to larger particles in the Accumulation mode which are more likely to be transported to drainage systems during precipitation, or coagulate further to be deposited on roofs and street surfaces. Volatile metals, especially those that form oxides (such as Cd, Pb and Zn) with boiling points at or below 1500°C, are vaporised during high temperature combustion processes such as incineration (Kaakinen *et al.*, 1975). They then condense onto the surfaces of ambient particles (Farmer and Linton, 1984), which may be transported with other suspended solids after deposition (Figure 2.2), becoming readily bioavailable under certain environmental conditions (low pH, as in acid rainfall) or dissolving in surface runoff (Farmer and Linton, 1984). This process of metal absorption is generally size dependant

as smaller particle condensation nuclei have a larger surface area to volume ratio (Demuynk *et al.*, 1976). Dry atmospheric fallout can be responsible for large proportions of street dusts (Section 2.2.3) (Luker and Montague, 1994). Bellinger *et al.*,(1982) have reported a study in Chicago where 70% of street dusts were attributed to atmospheric fallout, and Hedley and Lockley (1975) quote Figures of 116 tonnes km^{-2} per annum of street dusts arising from atmospheric sources.

A study in Leeds in 1982/3 by Clarke *et al* (1984) found that the main components of airborne particulates for an urban area are derived from the following sources:

- Soil-derived minerals due to re-suspension
- Elemental carbon from combustion processes
- Organic compounds (mainly partially or unburned combustion products)
- Ammonium salts from ammonia neutralisation of airborne acids
- Calcium sulphate from building materials, rocks and soils
- Sulphates from oxidation of SO_2
- Nitrates from oxidation of NO_x

Pollutants that are emitted directly into the atmosphere are known as primary pollutants (Quality of Urban Air Group, 1993). Others are formed in the air as a result of chemical reactions with other pollutants and atmospheric gases, and are known as secondary pollutants. CO and SO_2 are primary pollutants and ozone is a secondary pollutant. NO_2 can be both primary and secondary in that some NO_2 is emitted directly from power stations, incinerators and vehicle exhausts and some is formed from the oxidation of nitric oxide in the air. Sulphur Dioxide and smoke are the most widely measured pollutants and are still significant pollutants in urban areas, with the role and importance of acid aerosols being increasingly debated. Sulphur dioxide can be found naturally in the atmosphere as a result of volcanic activity however in the United Kingdom its

concentrations arise principally as a result of the combustion of fossil fuels. Coal, oil and gas all contain greater or lesser amounts of sulphur and therefore all produce SO_2 when burnt. Vehicles are not a significant source of SO_2 emissions since the sulphur content of petrol is small (0.04% by mass). Diesel however can contain larger amounts of sulphur (up to 0.2% by mass), which results in SO_2 emissions from diesel engined vehicles. Air pollution in industrialised areas such as Coventry can therefore result in the formation of acid rain, which is a dilute mix of sulphuric and nitric acid. Studies in Sweden (Morrison *et al.,* 1988) have recorded rainfall pH of between 3.8 and 4.9, and similar acid levels have been recorded in Scotland (Luker and Montague, 1994). In Britain more benign rainfall pH values (5.5-7.5) are experienced, though the impact on urban runoff may still be evident with pH levels in watercourses in Coventry reduced during rainfall events, as described in Chapters 5, 6 and 7.

Sources of heavy metals in the environment are either natural or anthropogenic, though in industrialised countries, and urban areas especially, anthropogenic sources make the predominant contribution to measured concentrations of most atmospheric trace metals (Demuynk *et al.*, 1976). Heavy metals occur in the atmosphere mainly in particulate form, originating from the mixing of finely divided materials from various sources. In many cases concentrations are at the limit of detection, and particulate analysis does not differentiate between the forms in which the metals are present. Consequently, our understanding of the speciation of metals in the atmosphere is still incomplete (Quality of Urban Air Group, 1993).

The common sources of some metal-bearing particulates are given in Table 2.4. Although air quality monitoring has increased in recent years both in terms of the number of pollutants monitored and the number of sites (HMSO, 2000), coverage of urban areas is still limited. Atmospheric particulates washed from the air by rain or deposited after

time will eventually form street dusts and be washed off buildings, roads, pavements and roofs to become incorporated into stormwater runoff (Sections 2.2.3 and 2.2.4).

Table 2.4 The common sources of some metal-bearing particulates (Quality of Urban Air Group, 1993)

Metal	Common Source Identified
Ni	Oil and coal burning. Occurs as Ni sulphate in fly-ash or nickel oxide
Cd	smelting of non-ferrous metals (CU, Ni and Zn). Fossil fuel combustion Waste incineration also produces a significant proportion
Cr	iron/ steel production and burning coal. Natural dusts (wind blown). Occurs mostly in the trivalent form, which is insoluble and not highly toxic. The hexavalent form is soluble, very toxic and carcinogenic.
Cu & Zn	burning fossil fuels and smelting. Tyre wear is a source of Zn & Cd.
Pb	Petrol combustion. Reduced with introduction of lead free petrol. Also production of ferrous and non-ferrous metals, fossil fuel combustion and waste incineration producing significant proportions of present total.

2.2.3 Traffic sources, street dusts and river sediments.

Road runoff contains a mixture of toxicants that are discharged, mostly untreated, into receiving waters. Typical pollutants include total SS, BOD, COD, heavy metals, hydrocarbons and bacteria of animal origin (Hvited-Jacobsen and Yousef, 1991). Urban or anthropogenic elements arise mostly from traffic, building construction and renovation, and the weathering and corrosion of building materials (Zobrist *et al.*, 2000; Charlesworth & Lees, 1997; Fergusson, 1990).

i) Vehicular Emissions

Road transport is an integral part of modern life (NSCA, 1999) and over 29 million vehicles, of which 24 million are private cars, are licensed to use UK roads (www.ace.mmu.ac.uk). This figure is likely to grow by 1.6% per year between 2000 and 2010 (Sunday Herald, 18 July 2004). Traffic causes local pollution problems filling streets with fumes and noise, and emissions from road vehicles causes pollution over vast areas of the country, even in rural areas, giving rise to 22% of total UK emissions of carbon dioxide (CO_2) (NSCA, 2006).

In the late 1960s in America alone, 90 million motor vehicles annually emitted 66 million tons of carbon monoxide, 1 million tons of sulphur oxides, 12 million tons of hydrocarbons and 6 million tons of nitrogen oxides, along with particulate matter and tetra-ethyl Pb (Ehrlich *et al*, 1972). Petrol is the major fuel type used for cars and light vans, with diesel making up 14% of the total (2001) and other fuel sources making up the remaining 1% (www.ace.mmu.ac.uk). The widespread use of Pb-free fuel in the 1980s and the introduction of catalytic converters in the 1990s have since led to a dramatic reduction in emissions of nitrogen oxides, as well as other harmful pollutants. Since January 1993, all new cars sold in the European Union have been fitted with a catalytic converter in accordance with EC Directive 91/441/EEC, and with increased use of Pb-free fuels, atmospheric Pb concentrations in the United Kingdom fell by 77% between 1976 and 1989 (Quality of Urban Air Group, 1993).

The type and concentrations of pollutants in vehicle emissions relies on a number of factors, (Quality of Urban Air Group, 1993):

- Fuel used
- Engine design/ maintenance
- Pollution control technology
- Driver behaviour
- Traffic conditions e.g. number of pedestrian crossings, traffic jams
- Vehicle speeds and stop-start manoeuvres
- The number and mileage (age) of different kinds of vehicles

Since 1990 all new cars can use unleaded petrol, which is essential for vehicles fitted with the catalytic converters required to meet the current limits (Road Vehicles (Construction and Use) Regulations 1986) required for HC, NO_x and carbon monoxide. The 'lean burn' engine burns cleaner than previous designs and is more fuel-efficient than engines fitted with catalytic converters (NSCA, 1999), however they are only just

beginning to meet EU emission standards (EC Directive 91/441/EEC). High speed motoring increases NO_x emissions and stop-start driving increases hydrocarbon emissions. In cities and towns, stationary vehicles at junctions and pedestrian crossings cause unnecessary additional pollution (Charlesworth *et al.*, 2003) and some European cities require that engines are turned off whilst waiting at traffic lights. Diesel fuel contains no Pb but diesel engines are a source of particulate matter and it is difficult to control emissions from diesel engines, once they are on the road.

Studies from the Transport Research Laboratory (Mackie & Davies, 1981) have shown a strong link between the number of nuisance reports about dust and dirt, and the number of lorries and changes of volume in total traffic flow. Road schemes that reduced traffic volume by 60%, on average, were found to reduce the number of people bothered by (i.e. reporting nuisance from) dust and dirt at home by half, from 56% to 28%. In one case the percentage of people bothered by dirt and dust was reduced from 55% to 16% following implementation of a scheme that reduced lorry traffic, but not the total traffic flow. This result is likely to relate to the more smoky and odorous nature of emissions from vehicles with diesel engines, which accounted for nearly 10% of vehicles in Europe at that time (www.engineeringtalk.com). In another case, an increase in traffic by 16% almost doubled the number of people bothered by dust and dirt from 33% to 63% (Mackie & Davies, 1981).

Dust and dirt from traffic will include direct exhaust emissions of particulates (mainly from diesels) and dust resuspended from the road by passing traffic. The resuspended material will include local soil material, products of vehicle wear (rust, tyre rubber etc) and de-icing salt in the winter months, and consist of coarse particles that settle quickly leaving fine particles suspended in the air (Namdeo *et al.*, 1999).

ii) Soiling on Roads

Vehicular emissions probably have the greatest impact on the levels of pollutants at ground level (Urban Air Group, 1993), although industrial and domestic activities also contribute to atmospheric particulate fallout. A City Centre location, adjacent to housing and industry, will provide a complex mixture of sources (Charlesworth & Lees, 1997).

A study in London (Moorcroft and Laxen, 1990) has shown that soiling levels alongside busy roads are on average double those measured away from the road on adjacent land, with up to 40% of solids dispersed within an area of up to 5 metres away (Colwill *et al.*, 1984). Turbulence from vehicle movements can mobilise and transport particles into the air, or conversely induce deposition, dependant upon their size grading. Dauber *et al.*, (1979), Harrison and Wilson (1985), and Herrmann *et al.*, (1994), showed that runoff from highways contains high levels of heavy metals, particularly in particulate form, suspended matter and hydrocarbons. Factors affecting the volume and nature street dusts and their potential for contaminating runoff of are discussed in 2.2.3iii) and 2.2.3iv).

iii) Heavy metal sources

Metals can exist in many forms; they can be attached to inert sediments, be contained in immiscible fluids, occurring as particles, soluble salts or insoluble compounds, and in organic, inorganic or complex forms, dependent on the prevailing redox and pH conditions (Luker and Montague, 1994). With the exception of the synthetic elements and nuclides produced by nuclear installations (e.g. Pu & ^{60}Co), all 'pollutant' metals are naturally present in the aquatic environment, although it is increased concentrations that present a threat to biota (Harrison, 1992). The term 'heavy metals' is an imprecise description that generally applies to metallic elements with an atomic weight greater than 40, but exclude alkaline earth metals, alkali metals, lanthanides and actinides (Rand *et al.*, 1995), although definitions relating to atomic number, toxicological properties

and specific gravity have all been cited (Duffus, 2002). The most important metals, from the point of view of monitoring water pollution, are Cd, Ni, Zn, Cu, Pb, Hg, and Cr (Environment Agency, 2000). Aluminium becomes important as a potential toxic metal in acid, and sometimes alkaline, waters. The likely sources of heavy metals in urban runoff are summarised in Table 2.5;

Table 2.5 Likely Sources of heavy metals in urban runoff
(Alloway and Ayres, 1997)

Metal	Likely Sources
Cd	Batteries, pigments and paints, plastics, printing and graphics, waste, wear of car tyres, corrosion of metals e.g. car bodies, fossil fuel combustion, medical uses, metallurgical industries
Ni	Batteries, metallurgical industries
Zn	Wear of car tyres, corrosion of metals e.g. car bodies, fossil fuel combustion, electronics, batteries, pigments and paints, plastics, printing and graphics, medical uses, waste, metallurgical industries.
Cu	Electronics, waste, metallurgical industries
Pb	Fossil fuel combustion, e.g. petrol, batteries, pigments and paints, plastics, printing and graphics, medical uses, metallurgical industries.

Quite apart from industrial sources, domestic wastewaters contain substantial quantities of heavy metals, because water has had prolonged contact with Cu, Zn or Pb pipework or tanks. Some forms of intensive agriculture can also give rise to specific metals, for example, Cu in pig feeds (Mance, 1987). Levels of soluble metals will tend to be highest, and toxicity thresholds lower (Table 2.10) in soft water areas, such as Scotland and the North-West of England, whereas the opposite applies for central, southern and eastern England (Luker and Montague, 1994).

Heavy metals in street dusts (Section 2.2.3iv) arise mainly from exhaust emissions, lubrication losses, and degradation of vehicle tyres, vehicle bodies, brake linings and motorway surfaces, and the use of de-icing compounds, and the contribution of metal corrosion to the Zn and Cd load in street dust is of great significance (De Miguel *et al.*, 1997). Corrosion of galvanised-metal structures can be responsible for concentrations of

up to 1.2% of Zn and 12ppm of Cd in the street dust around buildings undergoing renovation. (Cd, as an impurity of Zn, is found in significant amounts in galvanised metals). Even higher amounts 4.4% of Zn and 20ppm of Cd were found in the dust collected from under the metal ledges and balconies of old buildings (De Miguel *et al.*, 1997). Other heavy metals arise from such processes as the release of Cd and Ni from the combustion of fossil fuel, Cd release from weathered paint and pigment and Cu from the weathering and flaking of paints and pigments (Fergusson, 1990). As a result, urban pavement drainage often contains significant quantities of anthropogenic metal elements, including Cd, Cu, Pb and Zn. Morrison *et al.*, (1988) showed that developing anoxic conditions in gully pot traps could alter the Eh/pH environment enough to release bonded particulate metals into solution.

The origin of those elements associated with traffic (excluding Pb) lies primarily in the compounds used as additives in lubricating oils and diesel fuels, and in the metal wear caused by oxidation of lubricants. The influence of traffic on street dust and sediment composition is characterised by the presence of Zn and Ba, and to a lesser extent by Cu and Pb (De Miguel *et al.*, 1997). The presence of Zn and Ba were highly correlated (Pearson coefficient 0.973) in this case study, and both could be traced back to vehicles as a source (De Miguel *et al.*, 1997). Barium is used in detergents and dispersants, and oxidation and corrosion inhibitors in lubricating oils, for diesel and other combustion engines. Similarly Zn compounds have been used extensively as antioxidants and detergents for lubricating oils, and concentrations found in highway runoff are often associated with oil spills (Ellis and Revitt, 1982). Zinc and Cd are associated with the use, wear and disposal of various products such as vehicle tyres (WRc, 1993), and are examples of consumption related rather than process related or natural sources (Brown *et al.*, 1990; Macklin 1992). Oxidation of lubricating oils (exposure to air at high

temperatures) in a vehicle engine results in the formation of acids, alcohols and ketones, which are corrosive to metal. This causes wear of those metal parts, (mainly made from Zn, Cu and Cd bearing alloys) which come into contact with the oil (Drew, 1975). This process of wear and tear results ultimately in the release of those metals to the urban environment and their accumulation in street dust. Ni is resistant to corrosion (Street and Alexander, 1994) and therefore has widespread use from the production of office furniture, to the protection of motor vehicle bodies. It is however released to the environment during the wear of sinterised materials used in car oil pumps along with Cu and Mo (De Miguel et al. 1997).

Although Cu seems to accumulate from more than one source, (for example from roof drains, as discussed in Section 2.2.4), the high concentrations of Cu collected near to busy roads, and the high correlation found by De Miguel *et al.* (1997), between Pb and Cu in the street dust of Madrid (Pearson correlation coefficient 0.947) suggests that corrosion has a special significance for its dispersal (De Miguel *et al.*, 1997). They also found that the ratio of mean Pb concentration in the street dust of Oslo to that of Madrid (1:10), is almost identical to the ratio of the average Pb content of the petrol burned in both cities at the time of the study. This supports the idea that the gradual shift from leaded to unleaded fuel usage has resulted in a significant, and almost proportional, reduction in the concentration of Pb in dust particles under 100μm in urban environments. The addition of tetraethyl lead (TEL) to fuel was the main source of Pb in the environment until the widespread use of Pb-free fuels began in the 1980s, and Pb concentrations in the atmosphere fell by 77% between 1976 and 1989 due to initiatives to reduce the Pb content of petrol (Quality of Urban Air Group, 1993). The replacements for alkyl Pb in unleaded fuels are Olefins and MTBE. The combustion products of these

additives are gaseous, rather than particulate, and should not therefore contribute to highway runoff (Luker and Montague, 1994).

A number of factors have been reported that may influence metal concentrations in sediments from highway runoff, such as traffic density (Van Hassel *et al.*, 1980, Hares and Ward, 1999), the nature of intervening terrestrial vegetation (Laxen and Harrison, 1977), stream velocity and sediment composition (Murde and Ney, 1986) and physical mobilisation during high winter flows (Benes *et al.*, 1985).

Hares and Ward (1999) compared two sites draining the M25 London orbital motorway and Yousef *et al,* (1984) studied the composition of runoff from the Interstate 4 (I4) Highway in Orlando Florida. Hares and Ward (1999) found a higher level for some heavy metals, such as Pb, Cd, Cu, Zn, and Ni. These contaminant levels were not consistent with typical storm water concentrations found in the earlier American study. The storm water content for Cd (arising predominantly from tyre wear) and Cu from brake linings were higher at 14.1 $\mu g\ l^{-1}$ and 274 $\mu g\ l^{-1}$ respectively, than those identified by Yousef *et al.* (1984), as 52 $\mu g\ l^{-1}$ and 5 $\mu g\ l^{-1}$. The main difference between the studies is that the London orbital M25 motorway has a higher daily traffic density of 140,000 vehicles a day, whereas the Interstate 4 highway in Orlando, Florida studied by Yousef *et al.* (1984), carries 55,000 vehicles a day. The Pb content of the runoff from the M25 in 1999 was lower than the Yousef et al., 1984 findings, which probably reflect a reduction in the use of tetra-methyl lead (TML) and tetra-ethyl lead (TEL) additives in fuel since 1984, as discussed above, rather than an indication of traffic density effects.

Ellis and Revitt (1982) analysed the data compiled by a large number of authors and suggested that many papers do not identify a relationship between heavy metal loadings and traffic density as expected. The data for heavy metal loadings showed a large variability ranging over several orders of magnitude, and it was noted that sometimes

the metal loadings from urban and residential roads exceed motorway runoff figures. They conclude that though this may be attributed to an overlap in traffic density figures in some cases, it is more than likely indicating a source for heavy metal pollutants other than from motor vehicles, and that the variability in runoff concentrations may, in part, be due to nature of different road surfaces, hydrological conditions, (for example, total volume and intensity of stormwater) (Lee *et al.,* 2004) and street cleaning efficiency (Sartor *et al.,* 1974; Ellis, 1979).

The chemical form of Cd in stormwater runoff is such that approximately 50% of the total loading is present in a soluble form (Hares and Ward, 1999). For other metals, such as Cu, Zn, Pb, Cr and Ni, the percentage solubility levels are 20-40%, 30-50%, 1-10, 30 – 50%, and 50% respectively (Mesuere and Fish, 1989; Mungur et al., 1995). These qualities would potentially make Cu more easily removable in detention ponds, if installed as pollution prevention measures on a major highway, than Cd. In a study in the south of Sweden (Lundberg *et al.,* 1999), the concentration of heavy metals at the inlet and outlets to three detention ponds were compared against background levels. The results indicated that Cu and Pb are to a greater extent particulate associated, and Cd and Zn are found in the dissolved form (Lundberg *et al.,* 1999). The magnitude of variation according to season was at least 10 fold, but for Pb it was 100 fold. Metals were taken as filtered and unfiltered and it was concluded that most of the metals were present in the particulate phase (Lundberg *et al.,* 1999; Hewitt and Rashed, 1992). Ellis and Revitt (1982) sampled surface and gutter sediments from roads within N.W London for Cd Cu, Fe, Mn, Pb and Zn. They found that leachate levels show an extraction frequency of the following order:

Cd> Zn = Cu > Mn >Pb.

This indicates that highway sediments can act as effective sinks for Pb but not for Cd, which is efficiently released into the environment. In runoff profiles (Ellis and Revitt, 1982), the peak Cd leachate concentrations are reached after longer time periods due to the dependence of Cd on smaller particles. Other metals show no obvious dependence on particle size, which would suggest that all particle sizes are able to adsorb or release soluble metals from and to highway runoff. Charlesworth *et al.*, (2003) carried out sequential extractions on dusts collected in Coventry and identified Cd as the most bioavailable element, as it had the highest percentages bound to the operationally defined exchangeable sites and carbonates. Zn and Pb were mostly associated with carbonates and Fe/ Mn oxides, but not the exchangeable fraction. The vast proportion of Cu was found to be bound to organic matter and is therefore least likely to be made available to the environment under normal conditions. In this study (Charlesworth *et al.*, 2003), the bioavailability of heavy metals in street dusts in Coventry differed from some other data (Droppo *et al.*, 1998; Harrison *et al.*, 1981) in which the solubility of Pb was found to be greater than Cu. The results for Coventry street dusts were, however, very similar to those previously determined by Ellis and Revitt (1982), as discussed above, with additional findings for Ni. Cd was again found to be most readily available, with other heavy metals in order as follows:

Cd>Zn>Cu>Pb>Ni.

Very little metal found in Coventry street dusts was in the residual form or exchangeable fraction, which means that following a change in environmental conditions e.g. pH, there is a potential for metals, in particular Cd, to be released (Charlesworth *et al.*, 2003). Any metals released in this way would then be flushed through the drainage network into streams and other watercourses. Foster *et al.*, (1996) and Proffitt (1993) have shown that storm events can change prevailing environmental conditions by

buffering the effects of acid rain on the one hand, and by flushing through the urban system on the other. The result is the remobilisation of metals and the 'first-flush' effect of a storm after a dry spell (see Section 2.2.1).

iv) Street Dusts and Sediments

The composition, patterns of distribution and possible sources of street dust are not common to all urban environments, but vary according to the peculiarities of each city. De Miguel *et al.* (1997) investigated the common features and differences in the nature and origin of street dust as discussed above, through a series of studies in 2 widely different cities, Madrid and Oslo, between 1990 and 1994 (De Miguel *et al.*, 1997). Their results suggest that the chemical elements in street dust can be classified into 3 groups of origin: 'urban' elements (Ba, Cd, Co, Cu, Mg, Pb, Sb, Ti, Zn), 'natural' elements (Al, Ga, La, Mn, Na, Sr, Th, Y), and finally elements of a mixed origin which have undergone geochemical changes from their original sources (Ca, Cs, Fe, Mo, Ni, Rb, Sr, U). Soil re-suspension and mobilisation appears to be the most important sources of natural elements, while urban elements originate primarily from traffic and from the weathering and corrosion of building materials. The study (De Miguel *et al.*, 1997) suggested that natural elements seem dependant on soil type, which is incorporated into the street dust through the process of soil re-suspension. The concentration of these elements in the street dust is therefore heavily dependant on the composition of the geological material from which the urban soils are derived. In an urban area such as Coventry the underlying lithology may not, at first, seem to be an important factor in determining the quality of local stormwater, but the natural course of the River Sherbourne upstream of the culverted section, and open land in residential and urban areas and brownfield sites across the 52.86 km^2 catchment, will be subject to the impact of rainfall events, giving rise to erosion and contaminated runoff.

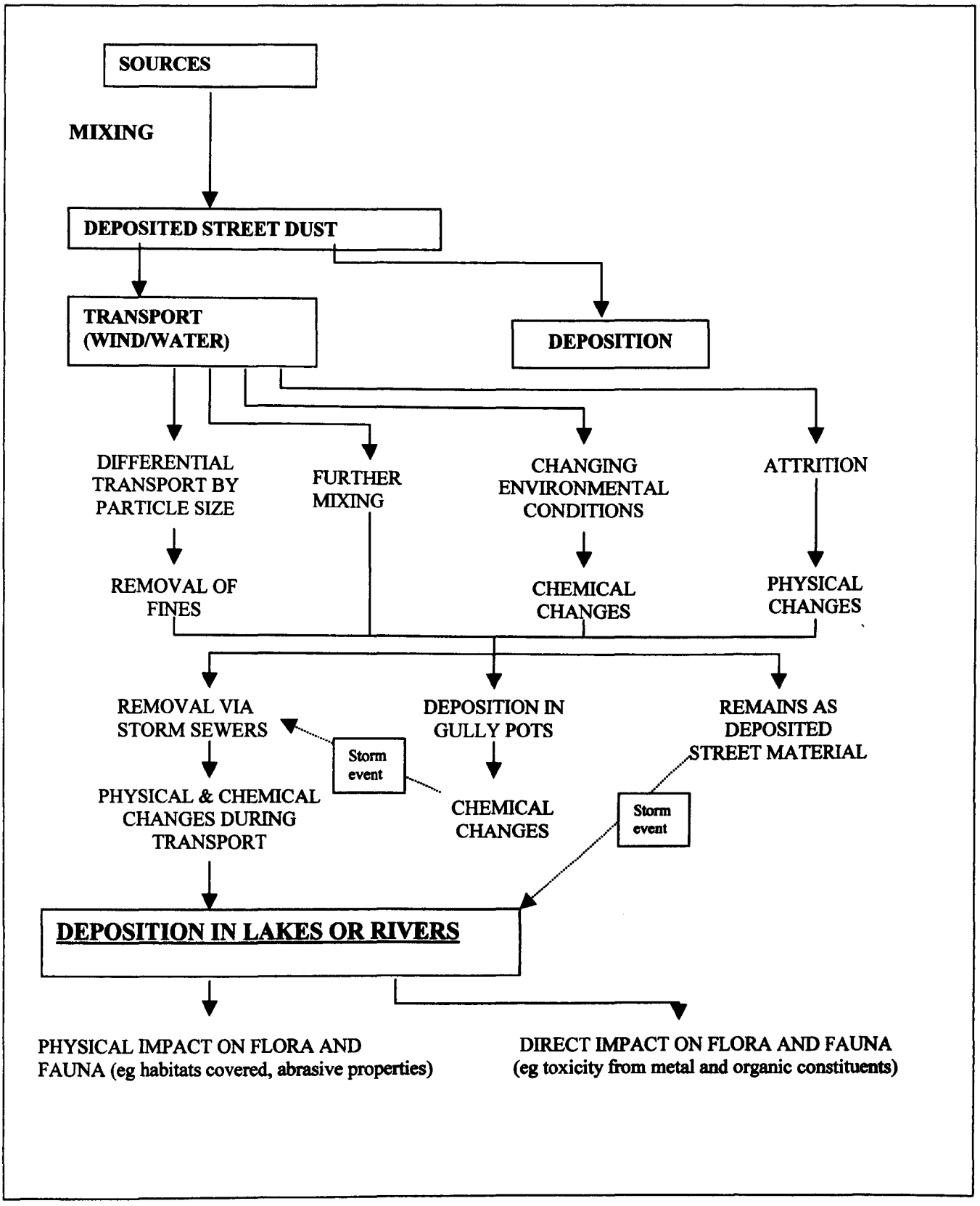
Urban sediments represent the net effect of urban activities upstream and as such are predominantly the result of storm water runoff events combined with the deliberate human or occasional natural supply of debris to the watercourse (Douglas, 1985). Stormwater sediments are therefore a heterogeneous mixture of particles, (Ellis 1989), and a City Centre location, adjacent to housing and industry, will provide a complex mixture of sources (Charlesworth & Lees, 1997). Coventry's vehicle manufacturing industry is world renowned with former factories belonging to Alvis, Massey Fergusson, Morris Motors, Jaguar engines, Standard and Triumph all producing vast quantities of vehicles and engines until recently. The Peugeot, Motor Panels, Rolls-Royce, London Taxis, Unipart Eberspächer and Dunlop plants continue to produce vehicle parts, and there are still a large number of metal finishing and engineering units supporting this industry in operation throughout the City. Active remediation and redevelopment of former brownfield sites has revealed high levels of heavy metal, organic and solvent contamination (Environment Agency, 2005), and dusts arising from contaminated soil removal to landfill, (and on-site treatment operations such as sorting and grading of soils), may still give rise to local variation in street dust concentrations for these pollutants. Street dusts in Coventry and Birmingham appear to retain evidence of historical contamination by the incorporation of eroded, contaminated soil (Charlesworth *et al.*, 2003). A number of studies have investigated the composition of street dusts and sediments in the Coventry area (Foster *et al.*, 1996; Charlesworth *et al.*, 2003; Proffitt, 1993; Charlesworth & Lees, 1999, 2001; Charlesworth & Foster, 1993). The distribution of sediments, and characterisation of particles and their associated contaminants were not studied in this thesis, but previous findings were used to consider possible sources for pollutants determined in monitoring local storm events.

Hewitt and Rashed (1992) identified that the majority of constituents in road runoff are associated with particulate material. These particulates may be washed away by rainfall and deposited as sediment in watercourses, as shown in Figure 2.2, which was adapted from Charlesworth & Lees (1999). Sediments and dusts transported and stored in the urban environment have the potential to provide considerable loadings of heavy metals to receiving waters and water bodies, particularly with changing environmental conditions (Morrison *et al.*, 1990) and river sediments can act as a means of storage, both in the short term as a matter of hours, and in the medium term, extending to decades (Forstner, 1983).

Charlesworth and Lees (1999) looked at sediment transport in the Coventry basin and identified 3 compartments or groups of sediments: sources, active (being transported) and no longer active (deposited). The sediments were fractionated into <2mm to reflect sediment deposited in lakes, and <63μm to represent natural and anthropogenic fluvially transported sediments. Transported material was dominated by the <63μm fraction, while deposited material was dominated by the <2mm fraction (Charlesworth and Lees, 1999). Research has shown that the most significant fraction of sediment, in terms of pollution, is < 63μm (Sartor and Boyd, 1972; Laxen and Harrison, 1977; Ellis, 1979), and although this constitutes only 6% of the total mass of sediment, it can constitute up to 50% of the pollution load of associated metals, hydrocarbons, COD, nutrients and herbicides (Collins and Ridgeway, 1980; Luker and Montague, 1994).

Figure 2.2 Flow chart showing movement of sediment in the urban environment

(Adapted from Charlesworth & Lees, 1999)



The Coventry study (Charlesworth and Lees, 1999) found that the highest proportion of each heavy metal is bound to different fractions in the sediment regardless of particle size, but that trends were found in terms of dominant heavy metals as the sediment moved through the source-transport-deposit cascade (Figure 2.2). The <63μm fraction contained the highest levels of all metals, and the <2mm fraction showed the greatest variability in relation to maximum and minimum levels. Overall Charlesworth and Lees (1999) found that in Coventry the deposits contained the highest concentrations of Cd, Cu and Pb, whilst the transported sediments contained higher concentrations of Zn and Ni (Charlesworth and Lees, 1999). The reduction in Cd and increase in Ni in the transported material may be due to dilution by organic matter or further addition of metal-contaminated materials.

In a study of heavy metal distribution on the River Severn flood plain, Zhao *et al* (1999) identified a pattern of decreasing grain size with distance from the river channel with Pb, Zn and Cu concentrations increasing over distance but Cd concentration decreasing sharply beyond a distance of 20 metres. They concluded that Pb, Zn and Cu are associated with silt and clay fractions while Cd has no significant association with particle size (Zhao *et al.*, 1999).

Research by Whipple and Hunter (1981) into the settleability of urban runoff in 1.83 m deep undisturbed waters confirms that Pb settles more readily (60-65% of total concentration settled in 32 hours), whilst Cu and Ni settle more slowly and with greater variability (20-50% of total in 32 hours) whilst Zn settled out the slowest at 17-36% of the total measured in 32 hours (Whipple and Hunter, 1981). Consideration of settleability and the likelihood of transport is important not only in considering sustainable urban drainage treatment systems such as attenuation ponds, swales or reed beds, but also to consider the incidence and impact of heavy metals during storm

conditions and their availability to flora and fauna in the urban environment. Carbonates and other exchangeable sites dominate in the binding of Cd, making it readily bioavailable as discussed above (Charlesworth *et al.*, 2003), Zn and Pb are mainly associated with carbonates sulphates and then Fe/Mn oxides (Harrison *et al.*, 1981), and the vast proportion of Cu is bound to organic matter, making it the least bioavailable heavy metal under normal conditions (Charlesworth *et al.*, 2003). The dominant binding site for heavy metal sources appears to be in the organic fraction of the sediment, whereas for transported material it is equally divided between carbonates and organic matter.

Deposited material seems to be more complex, with a combination of organic materials and carbonates and occasionally Fe and Mn oxides. The highest percentage per fraction (proportion) was again found to be independent of particle size except for organic matter, where the highest percentage for source material of a size less than 63μm is Ni, and for particles of less than 2 mm is Pb. This may impact on the results obtained in this investigation of the River Sowe catchment, as the sediments held in the shallow River Sherbourne corridor and those retained during low flows in the feeder culverts may under certain conditions such as storm events following dry weather periods, release pollutants including heavy metals to the sampled water column.

In general, differences in the metal binding capacity of the sediments and the presence of ligands (organic or inorganic which bind different metals to different degrees) will control metals concentrations retained in the sediments (Houba *et al.*, 1983), and their availability for uptake by resident species. Where heavy metals are not bioavailable, their presence in sediments may not significantly impact on the structure or diversity of the community, or lead to bioaccumulation of pollutants (Perdikaki & Mason, 1999; Lee & Jones-Lee, 1993). Apte and Gardner (1991) found that complexity decreases toxicity,

particularly for humic-metal complexes that are probably too large to pass across a semi-permeable membrane into a living cell. The large percentage of metals bound to organic matter and carbonates found in the Coventry study discussed above (Charlesworth and Lees, 1999) are therefore less bioavailable than those bound to exchangeable fractions. Low percentages of heavy metals in the exchangeable phase reduces immediate environmental risk, but metals bound to organic matter and carbonates can still constitute a threat should environmental conditions (such as pH or temperature) change.

2.2.4 Roof Runoff

Roof runoff is generally non-polluted, or not significantly polluted, compared to waste waters and urban runoff, as it should consist of fresh rainwater simply flowing over relatively inert materials, such as tiles, bitumen, less corrosive metals and concrete. This assumption that roof runoff can be considered as non-polluted stormwater, has generally led to the conclusion that it can be discharged directly into natural water bodies or groundwaters without impairing their quality and without the requirement for some form of treatment. In a field study by Zobrist *et al.* (2000) concentrations of total carbon, nitrogen, phosphorus and the heavy metals, were analysed in roof runoff, and it was identified that on inclined tiled and polyester roofs, runoff showed very high initial concentrations of the substances, declining rapidly to lower and more constant levels. For most constituents the concentrations were in the range of wet deposition after the first few mm runoff depth, and total loads in runoff corresponded to total (dry and wet) atmospheric deposition load. The flat gravel roof studied behaved differently in that rainwater was retained before overflowing, weathering the gravel and retaining most pollutants in the gravel layer. Most of the gutters and drains in the area studied (Zurich)

were made mainly of Cu materials, and they found that the corrosion of Cu in drains (5g m^{-2} $year^{-1}$) produced such high concentrations in roof water runoff, that direct disposal to watercourses could be questionable in certain areas.

Several research programmes have underlined very high heavy metal contamination from metallic or partly metallic roofing materials (Forster, 1996, Gromaire Mertz et al, 1999). In central Paris especially, experiments have shown that metal roofs are the main source of Cd, Pb and Zn loads in wet weather flows, due to corrosion (Gromaire et al., 2001). Gromaire *et al.* (2002) suggest that this result is likely to differ significantly from one site to another, depending on architectural characteristics. As indicated earlier, the Environment Agency now only routinely analyses for metals in watercourses downstream of known metal bearing discharges that are controlled by a Consent to discharge issued under the Water Resources Act, 1991 (H.M.S.O., 1991). There is currently no routine information available therefore, of the heavy metal component released during storms, or at any other time, from the urban area in the centre of Coventry. In this study, samples used to calibrate some continuous monitoring events for ammonium and DO levels, were also analysed for some heavy metals, namely Zn, Cd, Cr, Cu, Ni and Pb as discussed in Chapter 4. The results are shown in Chapters 6 and 7. Using flow data collected on site this information was used to produce within-storm analysis of pollution trends, and an estimation of the EMC (Section 2.1.1) of heavy metals produced during a storm event in Coventry was made, as discussed in Section 7.4.3.

The study by Zobrist *et al.* (2000), as discussed above, went on to examine the first flush effect from roof water, and determined that it was caused by one, or a combination, of 3 processes: 1) Matter deposited on the roof during the preceding dry weather period is washed off by falling rain; 2) weathering and corrosion products of the roof cover and

drainage system are washed off; and 3) contaminant concentrations in falling rain itself decrease with increasing rainfall depth, after the initial scavenging of particles, aerosols and gases by rain droplets (Zinder *et al.,* 1988). Calculated wash off loads of most constituents examined in the study ranged within a factor of 2.5 with respect to measured mean wet deposition concentrations and dry deposition rates, with the exception of NH_4^+(N), Suspended Particulate Matter (SPM), total Pb and total Cu. For Cu the estimated initial concentrations and wash off loads were considerably higher than corresponding measured values for wet and dry deposition, suggesting that the Cu roof and its drains acted as a source for Cu. It is again likely that metal parts were weathered and the products were washed off by rainwater (Förster 1996). The gravel roof retained most heavy metals and phosphorus, but not Cu, and it also supported some nitrification (see Section 2.3.1). This was possibly due to bacterial activity within the gravel media.

Boller and Häfliger (1996) estimated that in Switzerland about one third of Cu load in combined sewer systems originated from Cu used on roofs and in drain gutters. They suggested that if the first flush of 2mm runoff depth were diverted (e.g. to onsite treatment), the yearly mean concentrations for Cu, and the total loads would decrease slightly less than 30%.

The quality of runoff may therefore be improved or worsened in comparison to the composition of atmospheric deposition, depending on the kind of materials used for roof cover, the type of drainage systems, and their interaction with the atmospheric deposition itself. For building materials displaying open-air corrosion, runoff loads can be considerably higher. The studies discussed above suggest that if released in large quantities, these roof runoff pollutants will impact on the environment, (where no retention takes place), and that a local water quality problem could emerge at the discharge site.

The largest portion of Cu, Pb and Cd were present in a moderately reactive form, whilst most of the Zn occurred in the labile form (Zobrist *et al.,* 2000). Where these roof water discharges are fed directly into soakaways in an effort to replenish groundwater resources, the possible effect on the quality of the groundwater has to be considered. Metals will be retained in soils to different degrees depending on whether they are reactive or not, and may have the potential over time to cause localised contamination of private potable sources.

2.3 Contaminants and their ecological impact

In the River Sowe and River Avon catchments, at the commencement of this study, it was generally considered, based on routine sampling and the results of the River Avon continuous monitors (Section 3.6), that chemical impacts on the ecology of watercourses related predominantly to peaks of non-ionised ammonia, suspended solids and/or oxygen depletion (see Section 2.3.1). According to toxicological criteria (Borchardt 1992), limit values for endangering aquatic life are 50mg l^{-1} suspended solids, 4 mg l^{-1} O_2 and 0.1 mg l^{-1} ammoniacal nitrogen. Guidance levels and current statutory implementation (mandatory) levels for UK watercourses are given in Section 2.4.

Longer-term ecological damage from the presence or persistence of toxic or unstable compounds such as organics, heavy metals or ammonia may arise from a single large event such as a chemical spillage, emergency sewage discharge or large storm event, or from the accumulative effect of multiple intermittent discharges, e.g. storm overflows, contaminated drainage systems or domestic misconnections.

2.3.1 The impact of organic contaminants on the aquatic environment following storm events or sewage contamination

The presence of oxygen in water is essential to maintain higher forms of biological life. Clean surface waters are normally saturated with dissolved oxygen (DO) however

pollution from unstable organic wastes can rapidly reduce the oxygen content resulting in fish mortalities, anaerobic conditions, and in the case of potable waters, an insipid taste (Tebbutt, 1998). Game fish require at least 5 mg l^{-1} DO and coarse fish will not tolerate less than 2mg l^{-1}. Organic discharges may also contain large quantities of suspended solids, which can impact on riverbed ecology, particularly spawning areas (Tebbutt, 1998). This settlement of solids in areas with a lower flow regime such as wider or deeper stretches, may block sunlight from photosynthetic organisms, suffocate benthic invertebrates, bury eggs prior to spawning and line the gills of fish causing irritation, disease or death.

a) Chemical effects

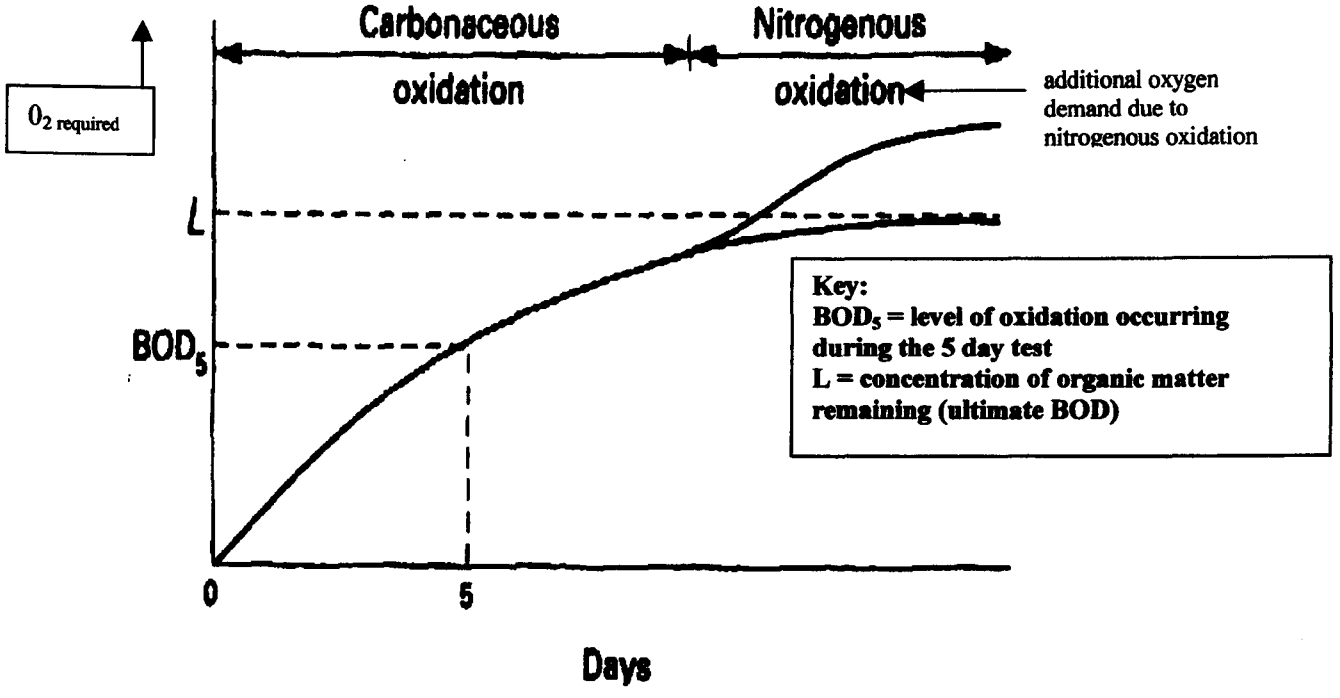
Organic pollutants consist of proteins, carbohydrates, fats and nucleic acids, which may be used by aerobic and anaerobic bacteria to facilitate growth and reproduction.

In the presence of oxygen aerobic oxidation takes place, with part of the organic matter being synthesized into new cellular material, and the remainder being converted to relatively stable end products. In the absence of oxygen, anaerobic oxidation will produce unstable end products such as organic acids, alcohols, ketones and methane. The nitrogen in these more complex compounds is liberated as ammonia on oxidation. In addition there is an oxygen demand for the further conversion of ammonia to nitrites and nitrates, in a process known as nitrification (Klein, 1972). The decay of proteins leads to the formation of ammonia, particularly in the presence of carbonaceous matter and little oxygen. This process is known as denitrification (Klein, 1972).

The Biochemical Oxygen Demand (BOD) gives a simple measure for the potential of biologically oxidizable polluting matter to remove oxygen in water. The value is obtained by incubating a 300ml sample of water for five days at 20^0C and determining the amount of oxygen used (Laws, 1993). No photosynthesis can occur during this

process, so the oxygen level should remain the same or decline. In practice the BOD is increased by the effect of the oxygen required for nitrification. Due to the slow growth rate of nitrifying bacteria, this effect does not normally become apparent in river samples for eight to ten days and would not show in a culverted urban watercourse like the River Sherbourne. In a treated sewage effluent containing large numbers of nitrifying bacteria the effect of nitrification on oxygen content can become clear after two days (Tebbutt, 1998). A typical BOD curve is shown in Figure 2.3:

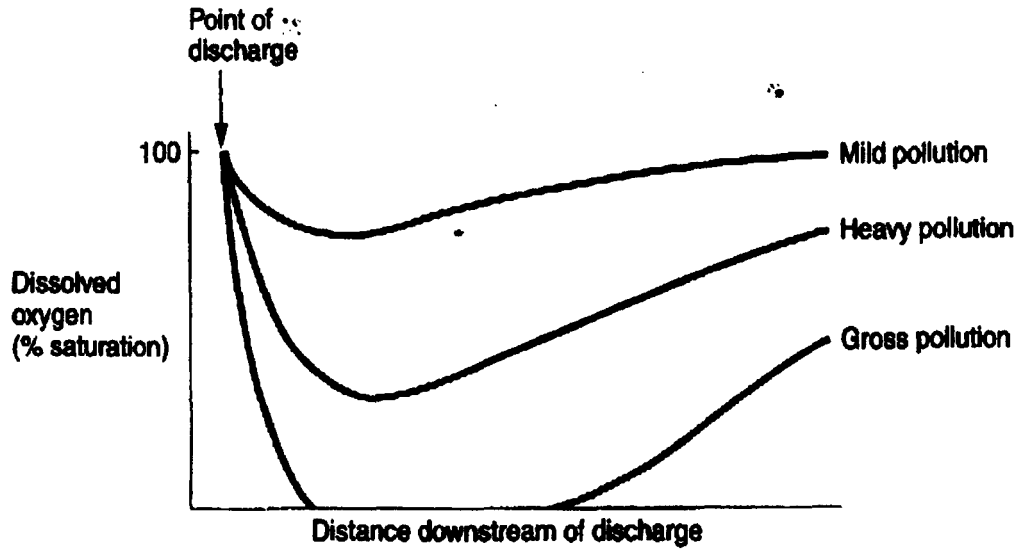
Figure 2.3: A Typical BOD curve *(after Tebbutt, 1998)*.



The y-axis in this diagram represents the amount of oxygen required for the biological oxidation of organic matter against time (days), in a water sample. When the carbonaceous source is almost fully oxidised, nitrification takes place, and further reduces the amount of DO present in the sample. During the BOD test the addition of allylthiourea will inhibit chemical nitrogenous oxidation, so that only carbonaceous oxygen demand is measured. Following gross pollution of a watercourse with organic

matter, such as would occur in the discharge of a large volume of untreated sewage, the DO will reduce significantly and levels of DO will sag over time as shown in Figure 2.4:

Figure 2.4: Oxygen sag curves (after Mason, 1996)



The reduction in oxygen concentration is determined by the nature and concentration of the organic pollutant, and therefore, the oxygen required for oxidation. The DO levels rise with increased distance downstream of the pollution through self-purification. Section 3.6 will explain how oxygen sag curves have been identified in both the River Sowe and Avon catchments. This study will examine the contribution of urban runoff from the river Sherbourne catchment, and demonstrate that organic content, both carbonaceous and nitrogenous, can peak to extraordinarily high levels during a storm event, and result in severe depletion of DO in the receiving waters.

A poor quality discharge such as untreated sewage effluent or storm sewage will contain a high concentration of ammonia, which may cause a further sag in the oxygen curve. This was demonstrated as part of the Urban Pollution Management project (Clifforde and Williams, 1997) in modelling the impact of urban and sewage flows in the River Avon and is described in Section 3.5.

Harremoës (1981) suggested that the degradation of organic matter can be divided into 2 phases;

i) A homogenous water phase degradation, which is instantaneous, and takes place due to adsorption of the substrate by heterotrophic bacteria

ii) A heterogenous degradation which is related to fixed surfaces in the river, whereby organic matter is removed by adsorption and sedimentation for later degradation (that is, after the pollutant plug has passed). He concluded that the delayed depletion due to sediment oxygen demand is the dominating phenomenon in small rivers. As a result of this, oxygen demand is distributed over the much larger volume of water that passes during the period a day or two after the event.

Disturbance of the sediments can lead to a rise to an increase in oxygen demand both during and after the events, which may explain why even in a smaller channel such as the River Sherbourne culvert, oxygen depletion can be prolonged, whereas it is more likely to be as a result of nitrogenous oxidation in the deeper pools of the River Avon (Section 3.6).

b) Effects on Biota

Storm events can generate natural increased sediment loadings within a watercourse (Figure 2.2), which may hide additional loadings from urban runoff (Luker and Montague, 1994). Potential impacts include;

- Blanketing of stream beds with sediment, affecting habitats and food supplies
- Direct toxic effects on stream fauna due to soluble pollutants such as heavy metals (Section 2.3.2) or ingestion of particulates
- Deposition of contaminated sediments. (These may require removal as special waste (Environment Protection Act, 1990) during dredging operations

- Increased turbidity and SS, affecting photosynthesis and causing damage to fish gills and filter feeders (Ellis, 1991).
- Depletion of DO concentrations due to oxygen demand (Section 2.3.1a)

The concentrations of suspended solids at which these effects occur vary with the species and the nature of the particulate matter. Invertebrate distribution patterns are profoundly influenced by the size of particles composing the substratum (Hynes, 1970). Mayfly nymphs with exposed abdominal gills (e.g. *Ecdyonorus* and *Ephemerella*) may be replaced by species with covered gills (e.g. *Caenis* and *Ephemera*). Insects that crawl along the substratum may generally be disadvantaged by species who require a soft substratum for locomotion such as leeches, oligochaetes and some molluscs. Therefore the input of even fine particulates can bring about major community changes or reduce the potential for improvement in diversity of species. Alabaster and Lloyd (1980) tentatively suggest that waters containing more than $80mgl^{-1}$ SS are unlikely to support good fisheries.

Reduced oxygen levels can lead to reduced fitness or even asphyxiation of organisms living in a stream. Bacterial populations will increase or decrease according to required optimal conditions as discussed. With heavy organic pollution, deoxygenation and low light conditions, algae are eliminated from rivers (Mason, 1996), but there is a gradual reappearance as conditions improve, and growth is stimulated by the large concentrations of nutrients present. Protozoa act as scavengers, feeding on bacteria and algae, and their population increases and decreases with the food availability (i.e. bacterial and algal mass) accordingly (Klein, 1972). The impact of Coventry's urban drainage system on the biological quality of the Rivers Sherbourne, Sowe and Avon is summarised in Table 3.1.

2.3.2 Heavy metal contamination – toxicity and impact

Potential sources of heavy metals and their release into the environment and bioavailability are discussed in Section 2.2.3. Some heavy metals are essential trace elements to living organisms (e.g. Cu and Zn), but become toxic at higher concentrations (Mason, 1996). Others such as Pb and Cd have no known biological function.

In general, metals may be listed in order of decreasing toxicity as follows (Abel, 1996):

Hg, Cd, Cu, Zn, Ni, Pb, Cr, Al, Co.

This sequence is very tentative, however, and toxicity can depend on species susceptibility and environmental conditions, mainly because of the effect on chemical speciation of the metal and the synergistic effects of other pollutants (Abel, 1996).

Water hardness, pH and temperature can directly affect the toxicity of heavy metals, since the environmental mobility and bioavailability of metals is largely dependent on their concentration in solution (Luker and Montague, 1994). Unpolluted natural waters can show a pH range of between 3.0 and 11.0 or more but those between 5.0 and 9.0 generally support a diverse population of aquatic species. Within this range, variations in pH can have major effects on the toxicity of pollutants such as ammonia and the availability of some metals (Abel, 1996). Low concentrations of soluble Pb may affect tadpoles, frogs and fish, such as minnows, stickleback and trout (Luker and Montague, 1994).

Many metals are known to accumulate in plant and animal tissues to very high levels causing a potential toxic hazard to the organisms themselves and to higher organisms in the food chain, which may consume them. The concentration of some heavy metal elements in freshwater causing mortalities for some invertebrates, salmonid (s) and non-salmonid (ns) fish (Crompton, 1997), are given in Table 2.6.

Table 2.6. Heavy metal concentrations causing mortality in some freshwater species ***(adapted after Crompton, 1997)***

Element	Invertebrates		Fish	
	Exposure Time (days)	LC_{50} ($\mu g\ l^{-1}$)	Exposure Time (days)	LC_{50} ($\mu g\ l^{-1}$)
Ni	-	-	Long term 100 15 4	500 (s,ns) 2200 (s, ns) 8000(s, ns) 35000(s, ns)
Zn	4 4 60 60	70 (D.magna) 10000 (annelids, larvae) 200-600 (snail, Ancyclus fluviatus) 2000 (amphipod, Allorchestes compressa)	500-1000 500-1000 4 4	260 (soft waters) 1050 (hard waters) 2600 (juvenile) 2400 (adult) rainbow trout (salmo gairdnera) 13300-33000
Pb	-	similar to fish	90 40 4	5500 900 1500
Cu	3 4 4	24 (crustaceans) 400-2000 (molluscs) amphipod (Allorchestes compressa)	72 30 6	80(s) 200(s) 250-400(s)
Cd	4 25	680 (crustaceans) 10 (Daphnia magna)	100 10 700	180(ns) 4000(ns) 2(s)

Key to table : s: salmonids ns: non-salmonids

As discussed in Section 2.2.3, local studies into street dusts in Coventry (Charlesworth *et al.,* 2003*)* have determined that heavy metals may be transported into watercourses during storm events, and may impact on the biodiversity of flora and fauna of urban watercourses. The Water Framework Directive (2000/60/EC) considers the ecological status of a watercourse by consideration of chemical and biological assessment, as described in Section 2.6. An understanding of local risks to achieving good ecological status, from heavy metal content in urban runoff is essential therefore to allow interpretation of biological assessment downstream of the culverted section of the river Sherbourne (Table 2.8), and address any problems identified by the results.

Objective 5, (Section 1.5) investigates whether emissions from traffic and industrial processes to air, as discussed above, contribute to an excess of heavy metals in storm runoff in the City. Spot samples and Auto-spot samples taken on the River Sherbourne at Humber Avenue, were analysed in Phase 3, to identify the concentration of heavy metals remaining in Coventry storm water during periods of rainfall after the main organic point sources were removed. The results are discussed in Chapter 7, and potential sources identified in Section 8.2. This investigation provides an opportunity to determine what concentrations of heavy metals are present in the watercourse, the possible sources of these pollutants, and whether they pose a risk to the watercourse in terms of biological impact, future amenity use or water quality standards under future legislation.

2.4 The role of the Environment Agency and current regimes for monitoring and control of water quality

2.4.1 The Environment Agency

The Environment Agency was formed in 1996 from the merging of the Local Waste Regulation Authorities, Her Majesty's Inspectorate of Pollution and the National Rivers

Authority. It has a statutory duty under the Environment Protection Act 1990, the Water Resources Act 1991, and the Environment Act, 1995, to protect or enhance the Environment, and part of this is to safeguard and improve the quality of rivers. Controlling the risks from pollution, and regularly monitoring the chemical and biological quality at specific locations or sampling points achieves this duty. The Agency has an extensive nationwide sampling programme, and assesses environmental quality over time to grade rivers in terms of both biological and chemical quality in accordance with the General Quality Assessment (GQA) Scheme (Section 3.1.6.1). River Quality Objectives (RQOs) have been assigned by the Agency to all rivers in accordance with the River Ecosystem (RE) Classification Scheme as outlined in Section 3.1.6.3. The Agency details the RQO for each river in its Local Contributions reports (formerly Local Environment Action Plans or LEAPs), which are reviewed annually (www.environment-agency.gov.uk). New objectives and target values for water quality under the Water Framework Directive (2000/60/EC) are yet to be defined, as discussed in Section 2.6.

2.4.2 General Quality Assessment (GQA)

Rivers and canals are split by the Environment Agency into stretches for the purpose of monitoring, and according to consideration of local factors such as river confluences, major discharges and accessibility for sampling. More than 1260 stretches, totalling over 6680km, are now sampled for chemical quality at least 12 times per annum (Environment Agency, 2000). Once every five years, biological sampling is also carried out in all stretches for the quinquennial survey, with two seasonal samples taken from each stretch. In the intervening years, only a proportion of the sample points are monitored. The methodologies for chemical and biological aspects of GQA are given in Table 2.7 and 2.8. The chemical grade is determined by assessing the concentrations of

ammonia, BOD and DO over a period of three years sampling (January to December). The overall grade for a river is determined by the worst of the three grades for the individual determinands. The grades are defined in terms of the 90 percentile for BOD and ammonia and the 10 percentile for DO. The fact that monitoring does not take place continuously gives a risk that a particular stretch of river, where close to the grade boundary, may be placed in the wrong grade. Where a river is sampled 36 times per annum there is an average risk of 19% that it is placed in the wrong grade. This figure is 22% for biology GQA (Environment Agency, 2000).

Table 2.7; GQA Chemical Grading (from Environment Agency, 2000)

Water Quality	Grade	Dissolved Oxygen (% saturation) 10 - percentile	BOD (ATU)[1] ($mg\ l^{-1}$) 90 - percentile	Ammonia ($mgNl^{-1}$) 90 - percentile
Very good	A	80	2.5	0.25
Good	B	70	4	0.6
Fairly good	C	60	6	1.3
Fair	D	50	8	2.5
Poor	E	20	15	9.0
Bad	F[2]	<20		

[1] as suppressed by adding allylthio-urea (see Section 2.6.1.1)
[2] i.e. quality which does not meet requirements of grade E

Table 2.8; GQA Biological Grading (from Environment Agency, 2000)

Water Quality	Grade	EQI for Taxa	EQI for ASPT
Very good	A	0.85	1.00
Good	B	0.70	0.90
Fairly good	C	0.55	0.77
Fair	D	0.45	0.65
Poor	E	0.30	0.50
Bad	F	<0.30	<0.50

A biological sample is taken by the Environment Agency in spring and another in autumn for each river stretch. To take account of seasonal variation, taxa found in the spring sample are added to any additional taxa found in the autumn sample. Two indices are then determined for each sample according to the number of different scoring taxa present and the average score per taxon (ASPT). These indices are then compared to the expected score for an unpolluted river with the same physical characteristics, using the mathematical model RIVPACS (River Invertebrate Prediction and Classification Scheme). The biological quality of a river is expressed as a ratio between the sampled value and the predicted value using RIVPACS. The ratio is known as the Ecological Quality Index (EQI) and is calculated for both the number of taxa present and the ASPT. A figure of 1 or more is an indication that the site has shown at least the expected number of taxa or ASPT to a similar site of natural water quality. The EQI for a site is compared against the standards shown in Table 2.8, and the site is assigned the lower of the two grades if different (Environment Agency, 2000).

2.4.3 River Ecosystem (RE) Classification Scheme

The Surface Waters (River Ecosystem) (Classification) Regulations 1994, (SI 1994 No. 1057), present a system for classifying the quality of waters according to potential future use, and allows for the setting of statutory water quality objectives under Section 83 of the Water Resources Act 1991, against individual stretches of water. This mechanism allows the Environment Agency to evaluate and control potential discharges to watercourses, by determining the appropriate discharge quality conditions to be imposed by a consent to discharge, given under the Water Resources Act, 1991. The River ecosystem classification comprises five classes, from RE1 to RE5, in decreasing quality. The criteria for each class are set out in **Table 2.9.**

Table 2.9: River Ecosystem Classification (Environment Agency, 2000).

Class	Dissolved Oxygen % saturation 10 %ile	BOD (ATU) mg l^{-1} 90 %ile	Total Ammonia mgNl^{-1} 90 %ile	Un-ionised Ammonia mgNl^{-1} 95 %ile	pH lower limit as 5 %ile upper limit as 95 %ile	Hardness mg l^{-1} $CaCO_3$	Dissolved Cu µg l^{-1} 95 %ile	Total Zn µg l^{-1} 95 %ile
RE1	80	2.5	0.25	0.021	6.0- 9.0	≤10 >10 and ≤50 >50and≤100 >100	5 22 40 112	30 200 300 500
RE2	70	4.0	0.6	0.021	6.0- 9.0	≤10 >10 and ≤50 >50and≤100 >100	5 22 40 112	30 200 300 500
RE3	60	6.0	1.3	0.021	6.0- 9.0	≤10 >10 and ≤50 >50and≤100 >100	5 22 40 112	300 700 1000 2000
RE4	50	8.0	2.5	-	6.0- 9.0	≤10 >10 and ≤50 >50and≤100 >100	5 22 40 112	300 700 1000 2000
RE5	20	15.0	9.0	-	-	-	-	-

The regulatory authority determines the appropriate river use (in accordance with current and historical use) by considering potential improvements that are considered cost effective and achievable, using best practice and available technology. A watercourse containing salmonid fish, or requiring little treatment for potable supply, would be considered as RE1 or RE2. There is no RE6 class as it is not appropriate to plan for poor quality watercourses with limited potential use. The objective classes for the River Sowe and River Sherbourne catchments are detailed in Section 3.3.

2.4.4 EC Freshwater Fish Directive (78/659/EEC) limits

As the River Sowe catchment, including the River Sherbourne is not classified as a fishery for cyprinid or salmonid fish, these fishery limits are not applied directly to the

watercourses. However, the River Avon becomes a cyprinid fishery at Bidford-on Avon (Figure 3.1), just below Stratford- upon- Avon, and the combined effects of the City of Coventry and the consented effluent discharges from Rugby, Coventry (Finham), Stratford and Warwick sewage treatment works, must be considered in meeting directive requirements. All of these Sewage Treatment Works have absolute maximum metals limits included in their treated effluent discharge Consents, as a result. Analysis of components not included in the General Quality Assessment sampling (Section 3.3), such as Zn, temperature and suspended solids are included in the investigations carried out in the River Sowe catchment as a result, and discussed generally in terms of fish directive standards and toxicity in Chapter 7.

The standards required under the EC Freshwater Fish Directive 78/659/EEC are given in Table 2.10. The areas of watercourse identified as fisheries have recently been reassessed by the Environment Agency, and as river quality improves in and below the River Sowe catchment, more and more stretches will be identified as potential or actual significant fisheries requiring protection under this and subsequent water quality Directives, including the Water Framework Directive (2000/60/EC), as discussed in Section 2.6.

Table 2.10: Standards Required by the EC Freshwater Fish Directive 78/659/EEC

Parameter	Salmonid Standard		Cyprinid Standard		Comments
	G	I	G	I	
Dissolved Oxygen (mg l)	≥9	≥9	≥8	≥7	50% of samples must meet this standard
		≥6		≥4	Absolute minimum
pH		6-9		6-9	Derogation allowed in naturally acidic areas
Un-ionised Ammonia (as NH3)mg l^{-1}	≤0.005	≤0.025	≤0.005	≤0.025	(0.004 mg l^{-1} and 0.02 mg l^{-1} as N respectively)
Total Ammonia (as N) (mg l^{-1})		≤0.78		≤0.78	Directive value = 1 mg l^{-1} as NH_4 or 0.78 mg l^{-1} as N. Derogation to 3 mg l^{-1} where healthy fish pop^n
Temperature °C		≤1.5		<3	Temperature change downstream of thermal discharge
		≤21.5		≤28	Limit may be exceeded 2% of the time. 10°C limit in breeding periods
Total Residual Chlorine (mg l^{-1} HOCL)		≤0.005		≤0.005	A suitable test is not yet available for this parameter
Total Zn (mg l^{-1} Zn) Water Hardness (mg l^{-1} CaCO3)					Derogation allowed in areas of high mineralisation, natural enrichment or abandoned mines
≤ 10	≤0.03			≤0.3	
> 10 and ≤ 50	≤0.2			≤0.7	
> 50 and ≤ 100	≤0.3			≤1.0	
> 100	≤0.5			≤2.0	
Suspended Solids (mg l^{-1})	≤25		≤25		Average concentrations
BOD (mg l^{-1})	≤5		≤8		UK values (Directive requires 3 mg l^{-1} and 6 mg l^{-1} respectively)
Total Phosphorus (mg l^{-1})	0.2		0.4		
Nitrites (as N) (mg l^{-1})	0.15		0.46		UK values (0.5 and 1.5 mg l^{-1} as NO2) Directive requires 0.01 & 0.03 mg l^{-1}
Phenolic Compounds (mg l^{-1} C_6H_5OH)					Must not be present in such concentrations that they affect fish flavour
Petroleum hydrocarbons					Must not form visible film. Must not give fish taste.
Dissolved Cu (mg l^{-1})	≤0.04		≤0.04		Depends on water hardness

G = Guide values, I= Mandatory (95% values except where stated)

As discussed above, the River Sowe is not designated as a Salmonid or Cyprinid Fishery but the Avon becomes designated below Bidford-on-Avon and is required to meet the above standards on 95% of the required 12 samples per year. The River Avon was

compliant under the EC Freshwater Fish Directive (78/659/EEC), as identified by the Environment Agency, 2000 report. Other Directives and associated Regulations applicable to the receiving waters are summarised in Table 2.11:

Table 2.11: Summary of Directives and Associated Regulations and Directions

Directive	Regulations and Directions
76/464/EEC	DOE Circular 7/89 (WO 16/89) The Surface Waters (Dangerous Substances) (Classification) Regulations 1989, SI No 2286, DS1 and DS2 (List I) The Discharge of Dangerous Substances Direction 1989. The Surface Waters (Dangerous Substances) (Classification) Regulations 1991, SI No 337, DS3 (List I) The Discharge of Dangerous Substances Direction 1991. The Surface Waters (Dangerous Substances) (Classification) Regulations 1997, SI No 2560, DS4 and DS5 (List II). The Surface Waters (Dangerous Substances) (Classification) Regulations 1998, SI No 389, DS6 and DS7 (List II).
78/659/EEC	The Surface Waters (Fishlife) (Classification) Regulations 1997, SI No 1331 The Surface Waters (Fishlife) Directions 1997.
75/440/EEC 79/869/EEC	The Surface Waters (Abstraction for Drinking Water) (Classification) Regulations 1996, SI No 3001. The Surface Waters (abstraction for Drinking Water) Directions 1996.

2.5 Urban Pollution Management

The Urban Pollution Management (UPM) methodology (FR/CL 0002. FWR, 1994) was developed over a period of 10 years, in response to the estimated requirement to spend £850 million in the 10 years to 2005, in addressing the issue of unsatisfactory storm overflows in England and Wales. The regulatory Agency (National Rivers Authority and then Environment Agency), the DoE and the regulated water companies developed the tools jointly, (using WRc to carry out the research), and ensured that the three aspects of sewage treatment; the sewerage system, the sewage treatment plant and receiving waters were considered as a whole in determining a cost-effective method of meeting the quality requirements of the receiving watercourse under the River Ecosystem

classification, as detailed in Section 3.1.6. The whole approach is designed to protect aquatic life from the impact of transient discharges from urban drainage systems, using specific environmental standards, and toxicological data from research on exposure to contaminants. The resultant short-term exposure limits are called Fundamental Intermittent Standards (FIS), as discussed in the next section. The UPM methodology (FR/CL 0002. FWR, 1994) can examine sewage flows from an identified catchment, treatment capacities at receiving sewage works, overflow frequency from known combined sewer overflows and pumping stations, and potential impacts on receiving watercourses under dry weather and storm conditions. The method can be used to set overflow weir heights, consent conditions at treatment works, spill frequencies at overflows and thereby determine storm storage capacity to protect aquatic life in watercourses of known quality, flow and potential. The UPM methodology (FR/CL 0002. FWR, 1994) was used to identify areas for improvement in treatment at Coventry (Finham) Sewage treatment works (Figure 3.3) following a marked deterioration of the River Avon during summer storms (Section 3.6) in 1996-7. The findings (Clifforde and Williams, 1997; Murrell *et al.,* 1998) led to significant improvements in the treatment facility, and receiving watercourse, as described in Sections 3.8 and 3.9.

2.5.1 Fundamental Intermittent Standards

Specific water quality standards for intermittent pollution events, such as discharges from combined sewer overflows or storm systems, have been developed as part of the UPM development programme (FR/CL 0002. FWR, 1994). They are known as Fundamental Intermittent Standards, and define the maximum concentrations of ammonia and oxygen permitted during a short duration, high-toxicity event. Traditional water quality standards, expressed as annual averages or percentiles, seek to protect

receiving waters from the impact of continuous inputs. The statistics of compliance with percentile standards do not allow for these short-term storm events, which may kill all aquatic life while not breaching the standard identified for long term water quality monitoring. There have been at least three previous approaches to developing short-term standards. The first of these came from the US Environment Protection Agency (USEPA, 1983). The standards include a short duration average concentration, or a maximum admissible concentration. For dissolved oxygen the minimum period is one day. The standards give no allowance for event duration and frequency as associated with wet weather events, where there may be a need to allow occasional extreme events. LC_{50} standards were developed very early in the UPM programme using published data. Standards produced predicted levels at which no more than 50% of the identified species would die for a given exposure period. The standards do not identify levels at which mortality is avoided in an average year. The standards use both LC_{50} and no-effect concentrations for continuous exposure conditions. Using toxicology data and experiments on fish and invertebrates, the UPM programme developed intermittent standards for ammonia and oxygen relating to storm events of different return frequency and duration. The standards for dissolved oxygen are given in Table 2.12:

Table 2.12: Dissolved Oxygen Fundamental Intermittent Standards
(After Foundation for Water Research, 1993.)

Dissolved Oxygen Concentrations ($mg\ l^{-1}$)			
Duration / Return frequency	1 hour	6 hours	24 hours
1 month	4.0	5.0	5.5
3 months	3.5	4.5	5.0
1 year	3.0	4.0	4.5

Intermittent standards are expressed as concentration/ duration thresholds, which are not to be breached more frequently than shown. For example, the dissolved oxygen concentration must not be allowed to fall below 4 mg l^{-1} for longer than one hour on average, with a monthly return frequency, for the river to be compliant with the standards. The thresholds apply when unionised ammonia concentrations are below 0.04 mg l^{-1}, due to possible synergistic toxic effects on fish of low dissolved oxygen and high ammonia concentrations. Unionised ammonia standards are given in Table 2.13:

Table 2.13: Unionised Ammonia Fundamental Intermittent Standards
(after Foundation for Water Research, 1993.)

Unionised ammonia Concentrations ($mgNH_3$-Nl^{-1})			
Duration / Return frequency	1 hour	6 hours	24 hours
1 month	0.150	0.075	0.030
3 months	0.225	0.125	0.050
1 year	0.250	0.150	0.065

Concentrations are upper thresholds, which apply when Dissolved Oxygen levels are above 5 mg l^{-1}. The thresholds also assume pH is above 7 and temperature is above 5^0C. The toxicity of un-ionised ammonia approximately doubles with a unit drop in pH and a 10^0C drop in temperature (Tebbutt, 1998). The impact of ammonium and low dissolved oxygen saturation levels are synergistic, and correction factors to take these conditions into account have been devised. The correction factors for dissolved oxygen standards under conditions of elevated un-ionised ammonia concentrations are given in Table 2.14.

Table 2.14 Correction Factors to be applied to Dissolved Oxygen standards
(*after Foundation for Water Research, 1993.*)

Un-ionised ammonia concentration (mg l^{-1})	Correction factor to be applied
<0.04	No correction
0.04 – 0.15	+ 1.0mg l^{-1}
>0.15	+ 2.0mg l^{-1}

The correction factors relating to ammonia under conditions of low dissolved oxygen, low pH and specific temperature are given in Table 2.15.

Table 2.15 Correction Factors to be applied to Ammonium standards in low dissolved oxygen, low pH and associated temperature conditions
(*after Foundation for Water Research, 1993.*)

Dissolved Oxygen concentration (mg l^{-1})	Correction factor to be applied to ammonium standards	
>5	No correction	
3 - 5	x 0.5	
<3	x 0.25	
pH	Temperature	
	<5^{0}C	>5^{0C}
>7	x 0.5	None
6 – 7	x 0.5	x 0.5
<6	x 0.25	x 0.25

It is unlikely that these correction factors will ever be critical, since under low pH and temperature conditions the proportion of total ammonia that is un-ionised is very small (Foundation for Water Research, 1993).

A river meeting these fundamental intermittent standards would be expected to support a mixed fishery. The standards are based upon the objective of long-term protection for storm events of up to one year return period. More extreme events will have a greater impact on receiving waters. The River Sherbourne investigation will be examined in respect of these intermittent standards to identify whether storm events exceed the suggested levels for short-term exposure.

2.6 The Water Framework Directive

The EC Water Framework Directive (2000/60/EC) establishes an integrated approach to the protection, improvement and sustainable use of Europe's rivers, lakes, estuaries, coastal waters and groundwater (UKTAG 2006, www.wfduk.org). It requires that all inland and coastal waters within defined river basin districts must reach *good status* by 2015, and defines the environmental objectives and ecological targets to achieve this (Foundation for Water Research, 2005). The definition of good status is currently being determined by the member states. The Environment Agency is the competent body for implementation of the Directive in England and Wales with SEPA identified for implementation in Scotland (Environment Agency, 2006). The Directive will:

- Define the meaning of 'good' status by setting environmental quality objectives for surface waters and groundwater
- Identify in detail the characteristics of the river basin district, including the risks to achieving good status posed by anthropogenic pressures (including urban runoff)

And require the competent body to:

- Assess the present water quality in the river basin district
- Undertake analysis of the significant water quality management issues, including abstraction pressures
- Identify a programme of measures (PoM) for each river basin district
- Consult with key stakeholders and other interested parties about the characterisation, proposed PoM, and cost –benefit analysis.
- Implement the agreed PoM, monitor improvements in environmental quality, review progress and revise water management plans.

The implementation timetable (www.defra.gov.uk) for the Water Framework Directive is given in Table 2.16.

Table 2.16 Water Framework Directive implementation timetable (DEFRA, 2006)

Date	Action
22 December 2000	Directive entered into force (article 22) bring into force the laws, regulations and administrative provisions necessary to comply with the Directive (article 24)
22 December 2003	Identify competent authority (article 3)
22 June 2004	Provide Commission with list of competent authorities (article 3) for each district, complete analysis of characteristics of the surface and groundwaters, review the environmental impact of human activity (industry, farming etc) and prepare economic analysis of water use (article 5)
22 December 2004	Establish register or registers of protected areas (articles 6 and 7)
22 December 2005	In the absence of agreement at Community level, of criteria for identifying significant and sustained upward trends in groundwater pollution and for the definition of starting points for trend reversals, Member States to establish appropriate criteria (Article 17(4)) In the absence of criteria at national level, trend reversal is to start at 75% of quality standards applicable to groundwater in existing Community legislation (Article 17, 5) Make operational monitoring programmes to ensure comprehensive view of water quality status within each river basin district (article 8) Publish and consult on a timetable and work programmes for the production of river basin management plans for each river basin district (article 14)
22 December 2006	In the absence of agreement at Community level, for substances included on the first priority list (see article 16), member states to establish environmental quality standards for all surface water affected by discharges of those substances and controls on principal sources of discharges (same obligation to apply 5 years after subsequent inclusion of a priority substance in the list, in the absence of Community agreement) (article 16)

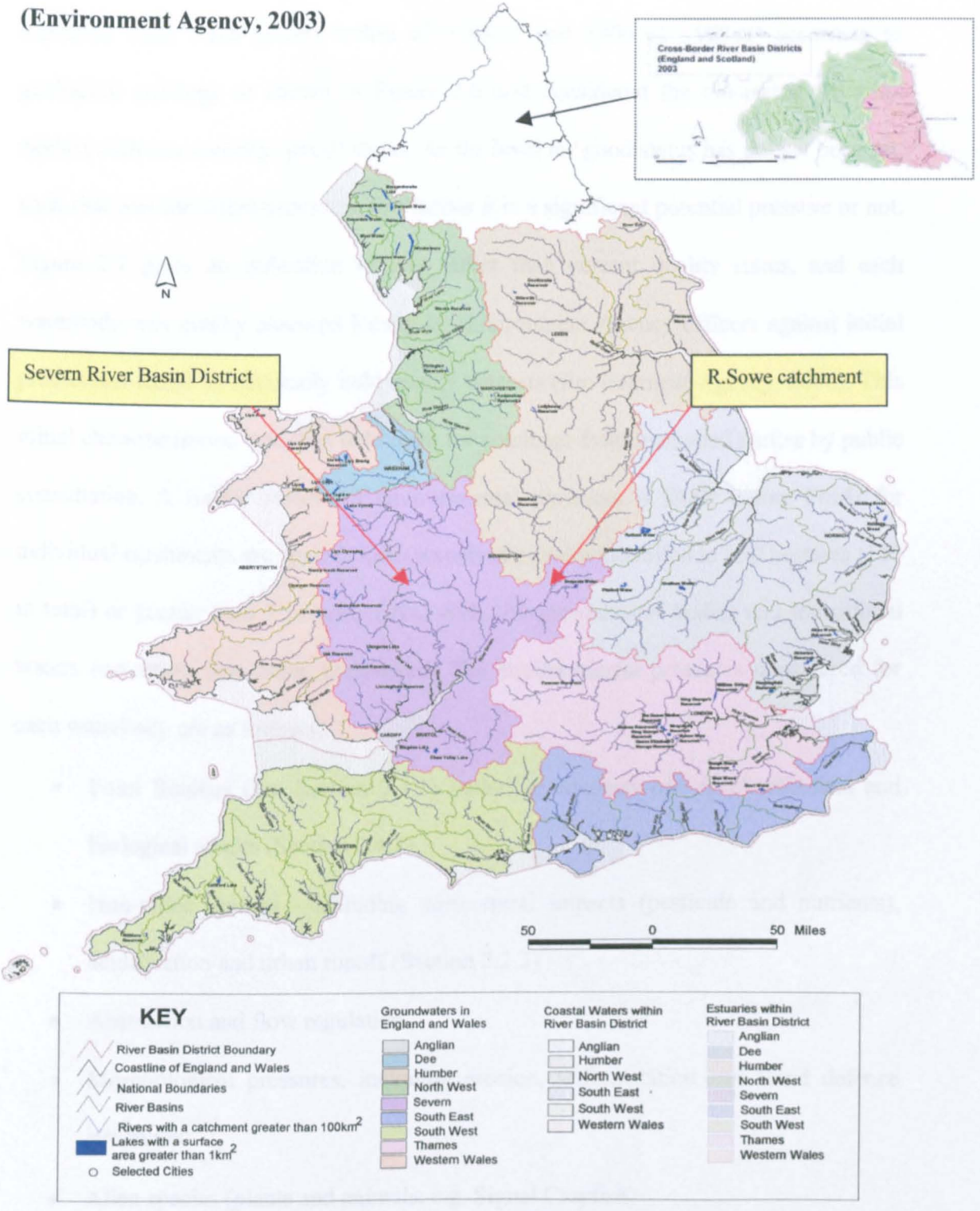
Table 2.16 Water Framework Directive implementation timetable (DEFRA, 2006) (continued)

Date	Action
22 December 2007	Publish and consult on an interim overview of significant water management issues for each river basin district (article 14)
22 December 2008	Publish and consult on drafts of the river basin management plans (at least 6 months to be allowed for comments in all the above cases) (article 14) establish programmes of measures in each river basin district in order to deliver environmental objectives (article 11)
22 December 2009	Publish first river basin management plan for each river basin district, including environmental objectives for each body of surface or groundwater and summaries of programmes of measures (article 13)
2010	Ensure proper water pricing policies are in place (article 9) make operational programmes of measures in each river basin district to deliver environmental objectives (article 11)
22 December 2012	Interim progress reports to be prepared on progress in implementing planned programmes of measures (article 15)
22 December 2015	Main environmental objectives to be met (article 4)
22 December 2015 & every six years thereafter	Review and update plans (with same consultation and interim reporting arrangements described above) (articles13,14 and 15)

2.6.1 Characterisation of river basins, water bodies and environmental pressures

The government has divided England and Wales into eleven River Basin Districts (RBDs), including two cross-border districts as shown in Figure 2.5:

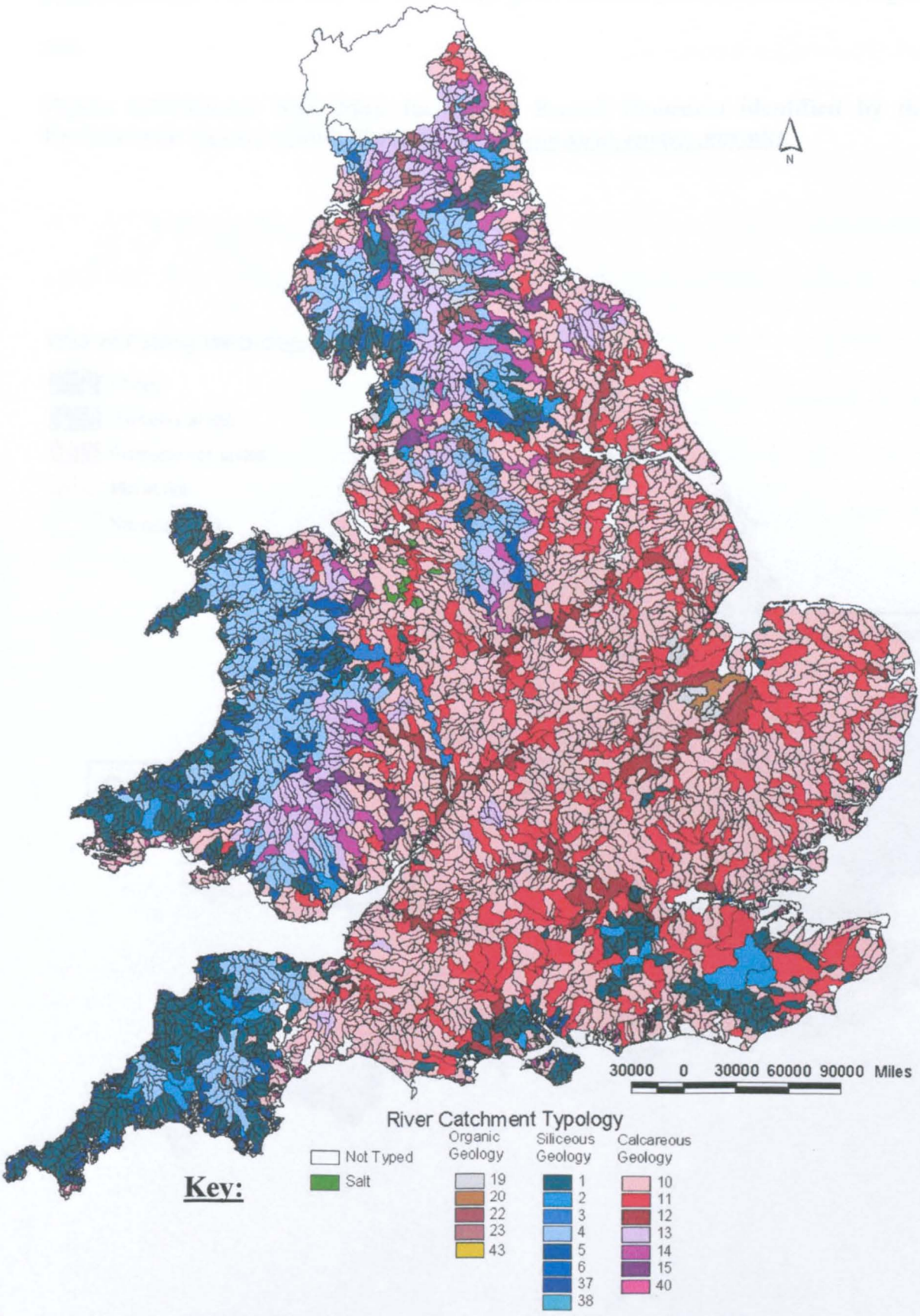
Figure 2.5 River Basin Districts in England and Wales (Environment Agency, 2003)



Because some RBDs are large and the environmental pressures complex, it will be necessary for planning purposes to subdivide them into smaller catchments, although it is anticipated by the competent body that there will be no more than 50 planning units at the catchment scale (Environment Agency, 2006). In 2004 the Environment Agency identified 5881 water (river) bodies of >10Km^2 and 1906 of <10Km^2 according to geological typology as shown in Figure 2.6 and considered the environmental risks against each one meeting 'good' status. As the level for good status has not yet been set, each risk was identified according to whether it is a significant potential pressure or not. Figure 2.7 gives an indication of risk rather than current quality status, and each waterbody was quality assessed locally by Environment Agency officers against initial predictions based on nationally held quality datasets (Environment Agency, 2006). This initial characterisation was then held open for comment from interested parties by public consultation. A further review of environmental pressures is likely before PoMs for individual catchments are agreed. Lake waterbodies were identified at >50 hectares (137 in total) or greater than 5 hectares (296) with 359 groundwater bodies and transitional waters (estuaries) also being considered. The environmental pressures considered for each waterbody are as follows;

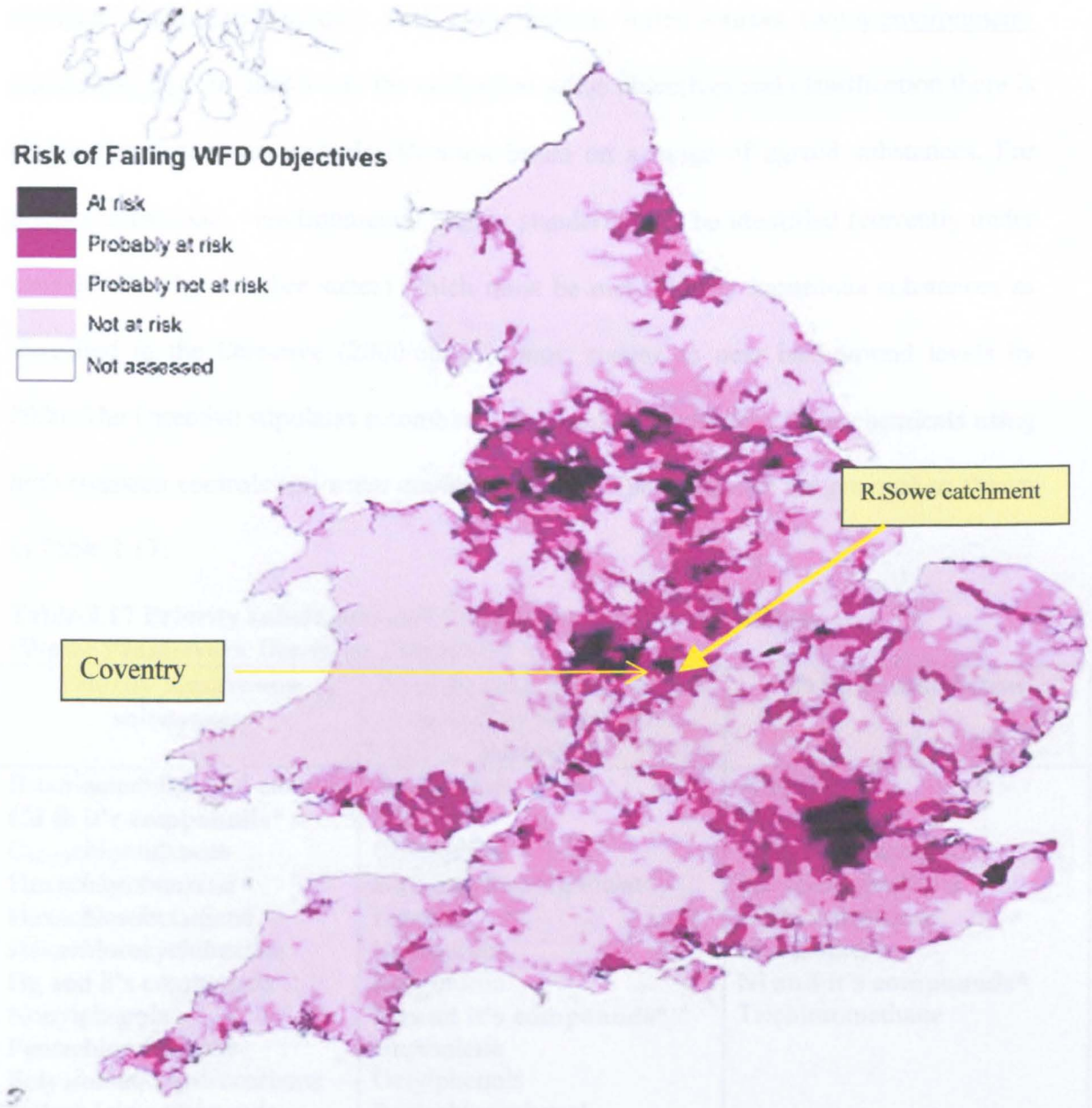
- Point Sources (see Section 2.1.1) including consents and GQA chemical and biological results (Section 2.4.2)
- Non-point sources - including agricultural impacts (pesticide and nutrients), acidification and urban runoff (Section 2.2.3)
- Abstraction and flow regulation
- Morphological pressures, including erosion, sedimentation and flood defence structures
- Alien species (plants and animals, e.g. Signal Crayfish)

Figure 2.6 River Catchment Typology (Environment Agency, 2003)



Maps have been produced by the Environment Agency, which show the risk of failing the water framework Directives for each environmental pressure (www.environment-agency.gov.uk). The risk map for Urban non-point sources (runoff) is shown in Figure 2.7:

Figure 2.7:National Risk Map for Urban Runoff Pressures identified by the Environment Agency (2004) (from www.environment-agency.gov.uk)



2.6.2 Classification of RBDs and waterbodies

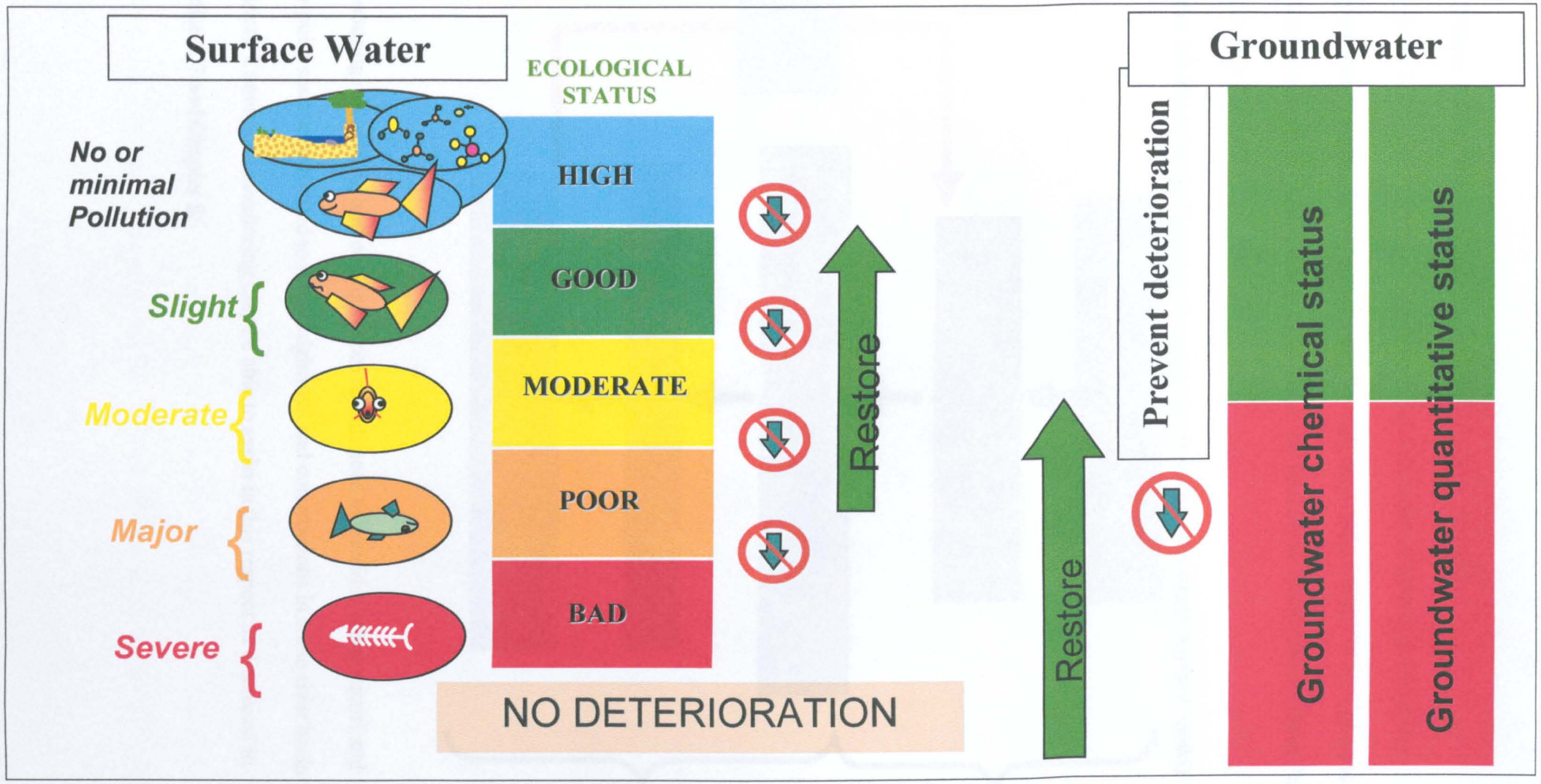
Surface water quality will be assessed using ecological and chemical status and groundwater quality will be assessed using chemical and quantitative status, as shown in Figure 2.8, with the objective defined as good status. Derogations against achieving good status will apply to heavily modified waterbodies (e.g. culverts and canals) and higher standards will be applied to protected waters such as recreational waters, nutrient sensitive waters, conservation sites and drinking water sources (www.environment-agency.gov.uk). In addition to the ecological status objectives and classification there is also a chemical status and classification based on a range of agreed substances. For priority substances environmental quality standards will be identified (currently under consideration by member states) which must be met. Priority hazardous substances as identified in the Directive (2000/60/EC), must reduce to near background levels by 2020. The Directive stipulates a combined approach to controlling these chemicals using both emission controls and water quality standards. The chemicals are grouped as shown in Table 2.17:

Table 2.17 Priority substances and Priority Hazardous substances (Water Framework Directive, 2000/60/EC)

Priority Hazardous substances	Priority substances subject to review as priority hazardous	Priority substances
Brominated diphenyl ether	Anthracene	Alachlor
Cd & it's compounds*	Atrazine	Benzene
$C_{10\text{-}13}$chloroalkanes	Chlopyrifos	Chlorofenvinphos
Hexachlorobenzene	Di(2-ethylhexyl)pthalate	1,2-Dichloroethane
Hexachlorobutadiene	Diuron	Dichloromethane
Hexachlorocyclohexane	Endosulfan	Fluoranthene
Hg and it's compounds	Isoproturon	**Ni and it's compounds***
Nonylphenols	**Pb and it's compounds***	Trichloromethane
Pentachlorobenzene	Napthalene	
Polyaromatic hydrocarbons	Octylphenols	
Tributyl tin compounds	Pentachlorophenol	
	Simazine	
	Trichlorobenzenes	
	Trifluralin	

*Heavy metals found during monitoring in this research are shown in bold type

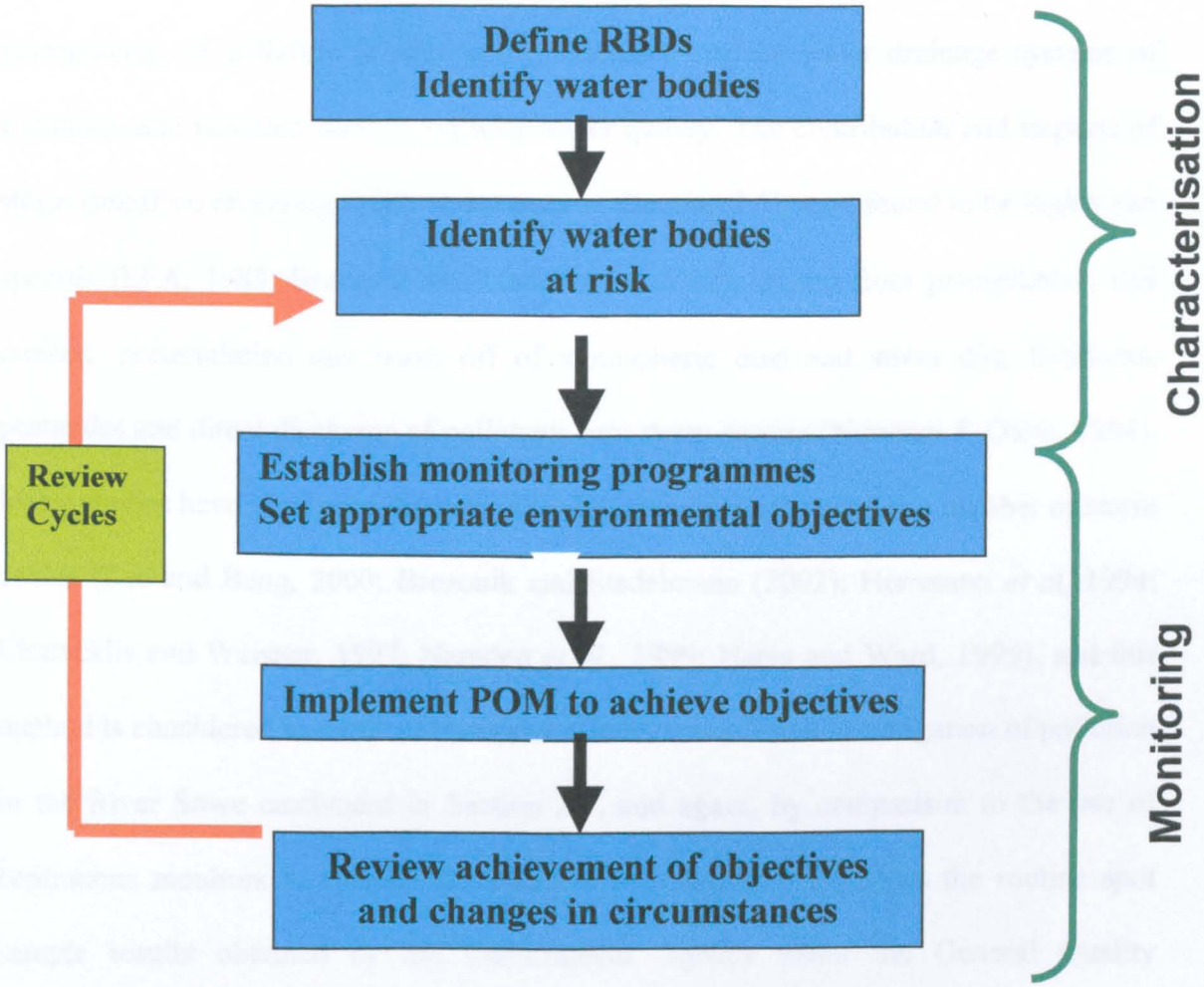
Figure 2.8 The Water Framework Directive concepts for water quality improvement (Environment Agency, 2004)



2.6.3 River Basin Management Plans and the review process

The Water Framework Directive introduces a six-year cycle of planning and action (Environment Agency, 2005), and running through each cycle is a continuous process of analysis and decision-making designed to shape the final River Basin Management Plan, as shown in Figure 2.9.

Figure 2.9 River Basin Planning Framework (from Environment Agency, 2004)



Monitoring of chemical and ecological status will need to consider urban runoff and non-point sources attributed to major highways and conurbations in some river basin districts. Continuous monitoring may be able to assist in this respect as discussed in Section 2.7 and Chapter 8.

2.7 Conclusions

This Chapter has identified pollution as emanating either from point or non-point (diffuse) sources (Chloe *et al.,* 2002), noting that when point sources are not easily identified, as in underground streams and drainage systems, they in effect become diffuse with regard to their impact on the aquatic environment. In Chapter 3 this theory is developed by examining the drainage issues and likely sources, (both continuous and intermittent), of pollution arising in the extensive surface water drainage systems of Coventry, and resultant impacts on local water quality. The contribution and impacts of storm runoff on receiving urban watercourses (Section 2.1) were found to be highly site specific (EPA, 1983; Brezonik and Stadelmann, 2002), arising from precipitation, soil erosion, accumulation and wash off of atmospheric dust and street dirt, fertilisers, pesticides and direct discharge of pollutants into storm sewers (Novotny & Olem, 1994). Many studies have employed discrete sampling techniques to monitor a number of storm events (Lee and Bang, 2000; Brezonik and Stadelmann (2002); Herrmann *et al,* 1994; Characklis and Weisner, 1997; Namdeo *et al.,* 1999; Hares and Ward, 1999), and this method is considered in terms of costs and effectiveness for an investigation of pollution in the River Sowe catchment in Section 2.1, and again, by comparison to the use of continuous monitors in Chapter 8 (objective 2). Chapter 3 examines the routine spot sample results obtained by the Environment Agency under the General Quality Assessment (Section 3.3), and details the seasonal problems identified by the use of discrete sampling and continuous monitoring in open watercourses. In Section 2.2 potential sources of urban runoff contamination from natural and anthropogenic sources such as soils, different land-use, traffic emissions and street dusts are investigated with reference to data gathered in many parts of the world. This reference material will be compared to the data gathered in the River Sowe catchment using the methodology

outlined in Chapter 4 to identify possible sources of local contaminants. Urban runoff was found to be more polluting in some cases (Laws, 1993) than treated effluent from Coventry Sewage Treatment Works (Section 3.7), and heavy metal contamination was generally found to be greater in urban areas (Arntson and Tornes, 1985), with commercial and industrial areas contributing more pollutants than open spaces, parks and low-density residential areas (Mulcahy, 1990; Bang and Lee, 2000).

The impact of long antecedent periods and summer storms with reference to the possibility of concentration peaks, known as the first flush effect, are documented in Section 2.2, and there is good evidence that pollution concentrations are greater after long periods of dry weather, in comparison to those determined in regularly occurring storm events (Lee *et al.*, 2004) The actual mechanism of how, when or if a first flush arises is still a matter for debate (Deletic, 1998; Saget *et al.*, 1995; Lee *et al.*, 2004) and, because of the even distribution of street dusts, and the continued wash off of the sediment throughout a storm event, a first flush effect is not always demonstrated when sampling road runoff. The methodology used for sampling short summer storms, particularly when employing flow triggered sampling techniques, could have an impact on whether the early impact of a storm is missed, and subsequently whether a first flush effect is identified in the data gathered (Deletic, 1998).

The nature of road surfaces, the imperviousness of the surrounding area (Klein, 1979), the intensity of the storm event (Lee *et al.*, 2004) and even the frequency of street cleansing (Sartor *et al.*, 1974; Ellis, 1979) are all stated to be contributory factors to the pollution profile of urban runoff. These factors are considered in discussion (Chapter 8) of the seasonal problems identified in the River Avon (Section 3.6), and the storm events monitored in Coventry drainage and the River Sherbourne (Chapters 4, 5, 6 & 7).

The impact of air pollution, and the potential for incorporation of heavy metal particulates of >2μm into street dusts and urban runoff were discussed in Section 2.2.2, and data (www.environment-agency.gov.uk) for the major airborne contaminants emitted from Coventry waste incineration plant which is located within the city perimeter, is examined in Section 3.9 as another possible source of locally found pollutants (Chapters 5 to 7). Other sources of airborne pollutants are also considered in this Chapter (Table 2.4, Quality of Urban Air group, 1993) and the contribution of road transport (NSCA, 1999; Ehrlich *et al.*, 1972) is discussed. The widespread use of Pb-free fuel in the 1980s and the introduction of catalytic converters in accordance with EC Directive 91/441/EEC have led to a marked reduction in vehicle emissions, but it is identified (Charlesworth *et al.*, 2003) that in cities and towns, including Coventry, stationary vehicles at junctions and pedestrian crossings can give rise to increased pollution, and that vehicular emissions probably have the greatest impact on the level of pollutants at ground level (Urban Air group, 1993). Dust and dirt from traffic will include direct exhaust emissions of particulates, and dust re-suspended from the road by passing traffic (Namdeo *et al.*, 1999). Section 2.2.3 identifies that heavy metals arise from exhaust emissions, lubricant losses (oil spills) and degradation of vehicles, tyres, brake linings and road surfaces (De Miguel *et al.*, 1997; Ellis and Revitt, 1982; Brown *et al.*, 1990; Drew, 1975) The corrosion and renovation of buildings (De Miguel *et al.*, 1997), atmospheric fallout and roof runoff also contribute to the overall heavy metal content of stormwater runoff (Zobrist *et al.*, 2000). Chapters 2 and 3 identify that trade effluents, (either by direct discharge or from overflowing foul sewers), and dusts from the remediation of contaminated land, can also be a factor for consideration of the Coventry data obtained during this research.

The impact of heavy metals on the environment will depend on their bioavailability, which in turn is a factor of solubility (Hares and Ward, 1999), environmental conditions (Foster *et al.,* 1996; Proffitt, 1993) and physical and chemical form (Lundberg *et al.,* 1999; Hewitt and Rashed, 1992; Ellis and Revitt, 1982; Charlesworth *et al.,* 2003). The results for Coventry (Charlesworth *et al.,* 2003) were similar to those found in London (Ellis and Revitt, 1982), with Cd most readily available to the environment followed by Zn, Cu, Pb and, in the case of the Coventry data Ni (in decreasing order of potential for release to the environment). The association of heavy metals with particulates (Zhao *et al.,* 1999; Charlesworth et al., 2003; Whipple and Hunter, 1981) are described in Section 2.2.3, and research on the transportation of these sediments and street dusts, particularly in Coventry (Charlesworth and Lees, 1999; Charlesworth *et al.,* 2003), may provide some explanation for the heavy metal results obtained during storm events monitored on the River Sherbourne in 2001 and 2003 (Chapter 7). Section 2.3 considered the effects of organic pollution on watercourses, and identified the impact of high Biochemical Demand (BOD) on a watercourse following a highly contaminated discharge, such as that from a sewer overflow or untreated sewage effluent. The result is to strip the watercourse of DO, and the presence of $NH_3(N)$ enhances this effect due to nitrification, as shown in Figure 2.3 (Tebbutt, 1998). The resultant oxygen sag (Mason, 1996), has been demonstrated in the River Avon following Summer storms with long antecedent periods, as discussed in Section 3.6. Objective 3 of this research considers whether the improvements carried out to drainage systems, as a result of this investigation, have reduced the impact from the City during storm events. Improvements to the River Sowe catchment watercourses are identified for chemical and biological quality in Section 3.3. The toxicity of heavy metals is discussed briefly (Section 2.3.2), and although the Rivers Sowe and Sherbourne are not currently classified as cyprinid fisheries, fish populations

present, particularly in the lower reaches of both watercourses, may be adversely affected by high concentrations of heavy metals in urban runoff (Section 7.2). The concentration of heavy metals determined during storm events in the River Sherbourne in relation to quality standards and potential water quality problems is discussed as part of meeting objective 5 in Chapters 7 and 8. This Chapter concludes with a consideration of the monitoring role of the Environment Agency, and the water quality standards and monitoring applied under the General Quality Assessment (GQA) scheme (Section 2.4.2). The results for Coventry watercourses are given in Chapter 3 (Section 3.3). The Urban Pollution Monitoring programme ((FR/CL 0002. FWR, 1994) is described to identify the process involved in consideration of intermittent discharges to open watercourses, and introduce the concept of intermittent quality standards based on toxicological impact. In Chapter 3 the application of this methodology to Coventry Sewage Treatment Works, and the requirement for further work to investigate the impact of urban runoff arising from Coventry surface water drainage is discussed (Section 3.8) the methodology for this investigation is outlined in Section 4.2.

Section 6 describes implementation of the Water Framework Directive (2000/60/EC), which requires an holistic approach to water management on a river basin district basis (Section 2.6.1), and will consider chemical and ecological status in achieving an objective of good status for most watercourses, lakes and groundwater. The anthropogenic impacts on the environment discussed in this Chapter, such as urbanisation and urban runoff, sedimentation, point and non-point sources, will all be considered under the Directive as pressures on the local environment, requiring (after consultation with interested groups), a programme of measures (PoM) to counter the risk of failing to meet the required objective. Chapter 3 (Section 3.10) outlines the main pressures identified for the Lower Severn area and specifically the River Sowe

catchment, and suggests that the use of the methodology for monitoring surface water drainage systems and culverted watercourses described in Chapter 4, could be applied to this and other major conurbations to identify anthropogenic environmental impacts.

Chapter 3 The River Avon and the River Sowe catchments

Introduction

The impact of pollution on watercourses has been well documented, as discussed in Chapter 2, but where the local impact of urban runoff is significant enough to give rise to public concern, and cause fish mortality on a regular basis, the mere knowledge that misconnections, intermittent discharges and stormwater runoff can cause problems, is not sufficient to ensure that a satisfactory solution can be identified. This research thesis investigates a pollution problem in an inland watercourse, the Warwickshire Avon, and the urban drainage catchment for Coventry, which feeds the headwaters of the Avon catchment via the Rivers Sherbourne and Sowe. This area was studied because there were known point pollution sources to be tackled in the city (Section 3.2) that could only be addressed at significant cost (due to their size and complexity), and with adequate proof of the pollutant impact to justify funding the investigation. The generally poor water quality in Coventry rivers, as identified by the regulator's routine monitoring programme (National River Authority and Environment Agency Section 3.3), also indicated that unknown intermittent and illegal discharges were contributing to the impact of Coventry's foul and surface water drainage systems on the River Avon, but it did not identify the contaminated streams and surface water systems responsible.

The Coventry drainage system is a good example of drainage in an urban environment, with culverted streams and watercourses, extensive surface water and combined sewerage systems, and the potential for intermittent discharge problems, which would be difficult to trace using conventional methods of spot sampling in open watercourses. The resultant problems in the receiving watercourse were so acute that deoxygenation of the River Avon caused annual mortality of fish species, as detailed in Section 3.6, and it was identified by the National River Authority and Severn Trent Water, that major

improvements in effluent quality at Coventry (Finham) sewage treatment works were required.

This decision led to an Urban Pollution Management (UPM) study (FR/CL 0002.FWR, 1994), quality modelling of the watercourse, and a planned upgrade to the treatment facility. The UPM study also identified Coventry's River Sowe catchment as a major source of contaminants that would remain after the proposed improvements to effluent treatment at Finham, although the scope of the UPM project did not extend to investigating these findings further. This chapter will describe the impact of urban rainfall on the River Avon catchment, and through an investigation of historical water quality data identify potential problem areas in the City. It identifies the locations of the watercourses affected by urban runoff that were investigated in this research (Sections 3.1 and 3.2), describing the history of the City of Coventry in terms of population growth, manufacturing importance and drainage improvements (Section 3.4). It provides details of General Quality Assessment (GQA) monitoring carried out in the area (Section 3.3), and the results obtained (Tables 3.1 and 3.2). Section 3.7 looks at the investigative monitoring carried out for determining the impact of Coventry's sewage treatment works and urban river systems in this area as part of the UPM study, and Section 3.6 describes the pollution problems identified in the River Avon following summer storms.

Previous work on the River Avon catchment (Clifforde and Williams 1997) showed that the contamination emanating from the City of Coventry during storm events had a marked impact on the quality of the receiving watercourses. The study was commissioned to investigate the impact of Coventry Sewage Treatment Works on the River Avon (Section 3.4), and was based on discrete samples taken during three rainstorm events using the Urban Pollution Management (UPM) methodology (Crabtree

et al 1995). This methodology, which has been developed to investigate pollution problems associated with multiple combined sewer overflows, does not however consider the impact of separate surface water sewers and any associated infiltration. The pollution loadings calculated by this UPM study do not take into account foul sewer misconnections, unknown combined sewer overflows, or illegal trade effluent discharges in the city which are occasionally identified in routine spot sampling of watercourses, or reported to water quality regulators as pollution incidents by members of the general public. In a second study on the chemical water quality of the catchment, the River Avon Eutrophication project (Foster *et al* 1998) identified an unusually high level of phosphate in the waters from the River Sowe catchment upstream of Coventry (Finham) Sewage treatment plant. These high concentrations may be due to high levels of untreated sewage effluent entering the watercourse from undetermined sources. Both projects identified further research work was required on the River catchment upstream of Coventry Sewage Treatment Works, to identify additional sources of pollution that were causing fish mortality each summer in the receiving watercourse (see Section 3.6). Because of the culverted nature of the City Centre watercourses in Coventry, it had always been difficult for the Regulatory bodies such as the National River Authority and the Environment Agency to capture intermittent pollution incidents for analysis using spot samples and biological sampling alone. A continuous assessment of the water quality for each culverted watercourse was required, transferring the application of mobile continuous monitoring technology previously used only in open watercourses and on troublesome consented effluent discharges, to the hidden stretches of surface water sewer and culverted watercourse in the City. To satisfy the aims and objectives identified in Chapter 1, this research has gathered data from culverted drainage systems (and the open watercourses affected by them) in Coventry, which will relate to all river

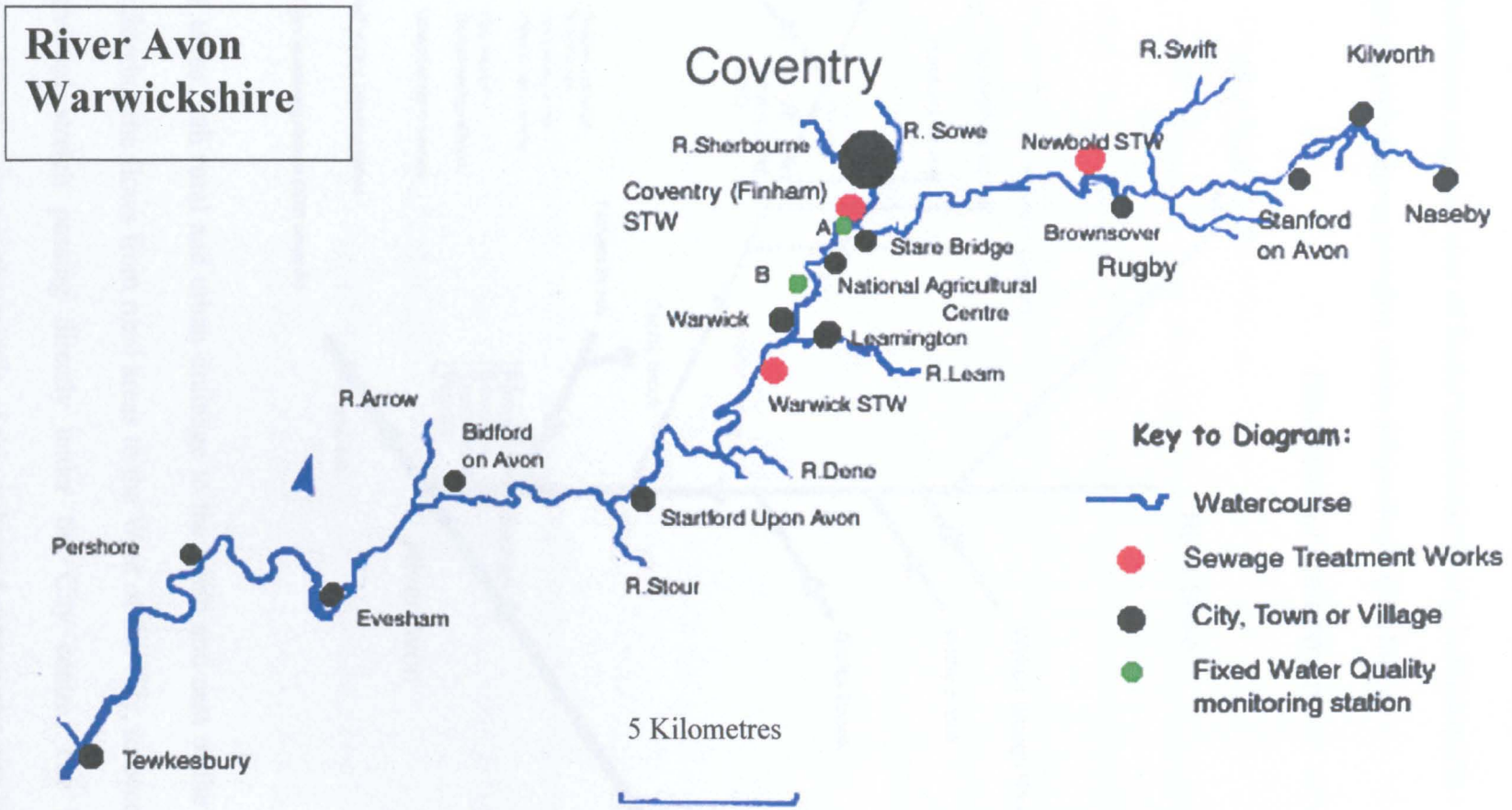
catchments similarly affected by runoff from large urban areas and subject to the effects of illegal storm overflows, misconnections and illegal trade effluent discharges. This will be particularly useful in assessing the ecological impact of urban runoff for quality assessment under the Water Framework Directive (2000/60/EC), as described in Section 3.11.

3.1 The River Avon catchment

The 100 mile-long River Avon in Warwickshire (Figure 3.1) rises as a tiny stream trickling from the 185m contour near the centre of the village of Naseby, in the Northamptonshire uplands; a long continuation of the Jurassic ridge of Limestone, which reaches from the Humber to the Dorset Coast (Kolsky, 1998). Just south of Kilworth the river turns sharply southwest to Stanford Reservoir, which is used by Severn Trent Water Ltd for potable supply. As it passes into Rugby at Brownsover the river has fallen only 4m in the last 5.6 kilometres (Kolsky, 1998). Before it runs through the improved flood defence features of the Brownsover floodplain, it is again abstracted for potable supply by Severn Trent Water Ltd. The rural river is then transformed by the addition of the Clifton Brook and the River Swift into a fast flowing urban river with a moderate degree of treated sewage and trade effluents. It then receives 18,670 m^3 per day (dry weather flow) of treated sewage effluent from Rugby (Newbold) STW. Above the confluence with the River Sowe at Stare Bridge, built in medieval times, there are healthy populations of Brown Trout. The watercourse reaches the National Agricultural Centre, and is joined by the River Sowe catchment (see Section 3.1). The River Avon becomes deeper and darker, forming a series of deep pools, and receives treated sewage effluents from a number of hotels before reaching the Saxon Mill restaurant at Guy's Cliffe. This is the location of the Saxon Mill continuous quality monitor, which was taken out of service in 2003, and the site of fish mortality in

previous years due to oxygen depletion following summer storm events, as discussed in Section 3.6. The River flows on through Stratford, Evesham and Pershore (being used for agricultural abstraction, navigation and recreational purposes), to join the River Severn at Tewkesbury, taking on board the Rivers Leam, Stour and Arrow as it goes. At Purton river water is abstracted to feed the Gloucester and Sharpness canal, which, in turn, is used as a potable water supply by the Bristol Water Company.

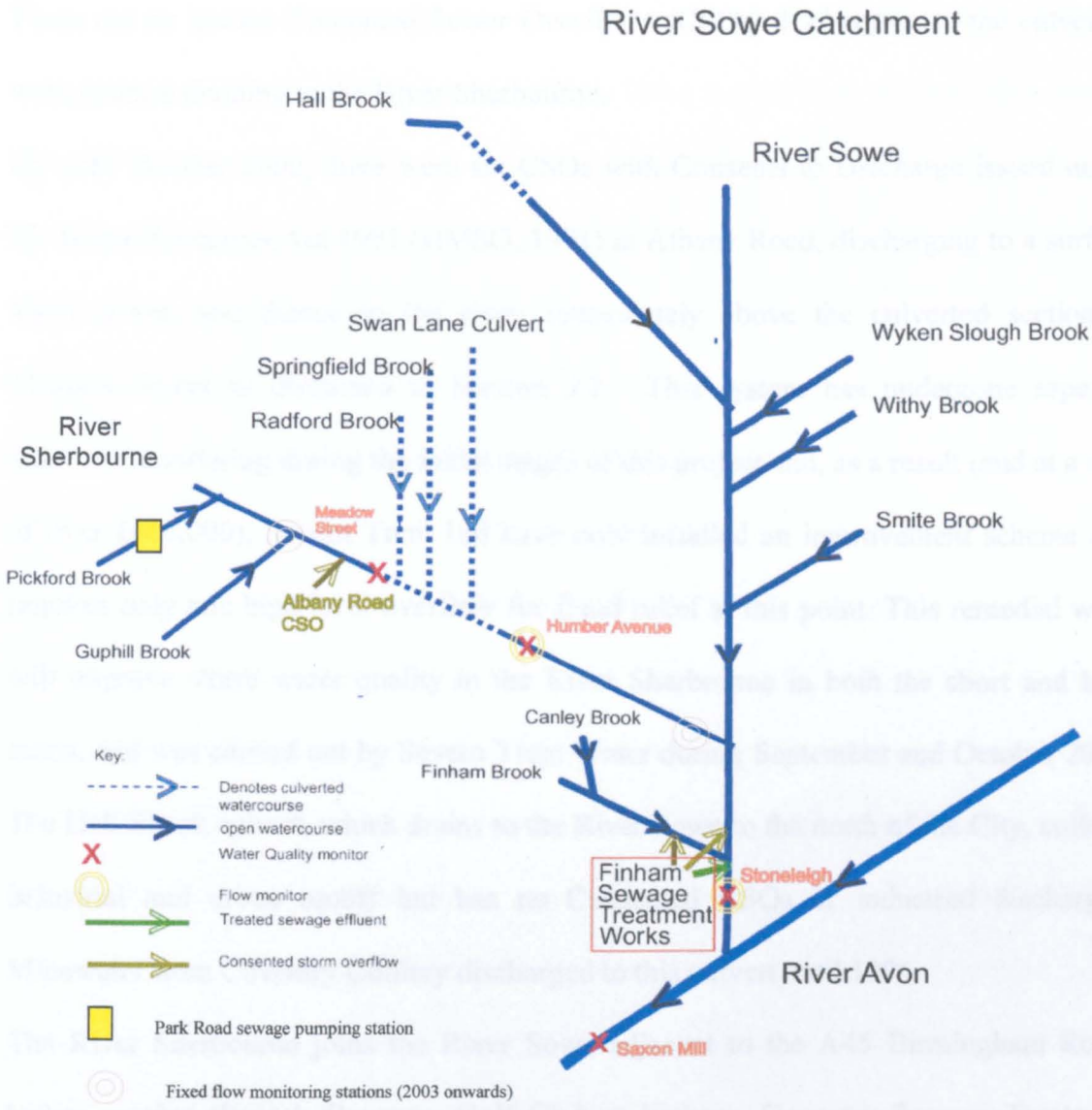
Figure 3.1 The River Avon Catchment *(after Kolsky, 1998)*



3.2 The River Sowe and River Sherbourne Catchments

Coventry is drained by the River Sowe catchment, which consists of the River Sowe, the smaller River Sherbourne and a number of feeder streams as shown in Figure 3.2:

Figure 3.2 Diagrammatic Representation of the River Sowe Catchment



The River Sowe takes both rural and urban drainage to the north and east of the City, whilst the River Sherbourne flows from rural areas to the West of the City, to become a 3 kilometre culverted stretch passing directly under the City centre. The River Sherbourne is open for 10 metres in the middle of this culverted stretch at a site known as The Burges. Above this point the culverted Radford brook joins the system whilst

immediately below The Burges the far-reaching river culverts, known as Springfield Brook and Swan Lane culvert, contribute mostly industrial and urban runoff to the system. In addition there are several major (unnamed) surface water drainage systems with evidence (in the form of sewer rags, faeces and paper) of foul sewage content. There are no known Combined Sewer Overflows (CSOs) discharging to the culverted watercourses draining to the River Sherbourne.

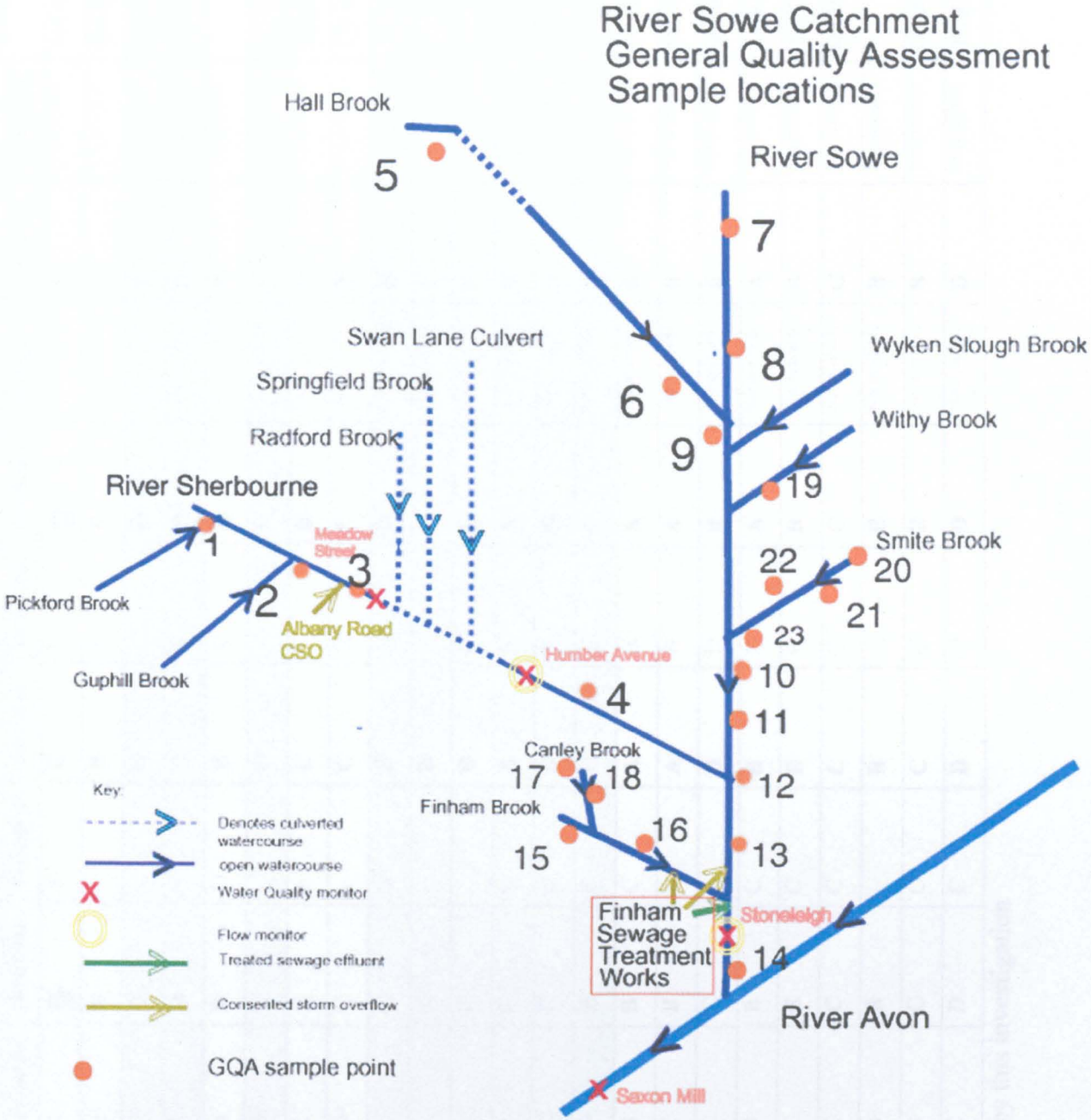
Up until October 2000, there were six CSOs with Consents to Discharge issued under the Water Resources Act 1991 (HMSO, 1991) at Albany Road, discharging to a surface water sewer, and thence to the river, immediately above the culverted section at Meadow Street as discussed in Section 3.2. This system has undergone separate intensive monitoring during the initial stages of this project and, as a result (and at a cost of over £400,000), Severn Trent Ltd have now installed an improvement scheme that requires only one high-level overflow for flood relief at this point. This remedial work will improve storm water quality in the River Sherbourne in both the short and long terms, and was carried out by Severn Trent Water during September and October 2000. The Hall Brook culvert, which drains to the River Sowe to the north of the City, collects industrial and urban runoff but has no Consented CSOs or industrial discharges. Minewater from Coventry Colliery discharged to this culvert until 1996.

The River Sherbourne joins the River Sowe adjacent to the A45 Birmingham Road, before passing through Coventry Golf Club at Finham. Coventry Sewage Treatment Plant discharges up to $90Mld^{-1}$ of treated sewage effluent into the river immediately downstream of the Finham Brook confluence. There were Environment Agency continuous water quality stations, at Stoneleigh on the River Sowe, and at Saxon Mill on the River Avon as shown in Figure 3.2. The station at Stoneleigh could also record river flows. Both water quality monitoring stations were decommissioned in September 2003.

3.3 Routine water Quality (General Quality Assessment) sampling

Before investigating the quality of the watercourses in the River Sowe catchment using continuous monitoring and automatic samplers, it is important to identify the current routine General Quality Assessment programme (GQA) carried out by the Environment Agency in the area, and consider the reported data from this occasional spot sampling methodology, as given in Table 3.1. The Rivers Sowe and Sherbourne, and some of their tributaries, were spot sampled 12 times per annum by the Environment Agency, to determine the quality of the watercourses over a three-year rolling period. The River Sowe catchment has ten General Quality Assessment (GQA) points regularly sampled by the Environment Agency for water quality and biological assessment, as shown in Figure 3.3. The results for routine sampling by the National Rivers Authority and Environment Agency, between 1995 and 2002, for the River Sowe and River Sherbourne are given in Table 3.1. The results for the River Avon, above and below the confluence with the River Sowe, are given in Table 3.2. The results show an improvement in water quality on all of the river stretches monitored by this study. The quality of the River Sherbourne and Pickford Brook (Figure 3.2) above the study area for this research have deteriorated, mainly due to discharges by private sewage treatment plants receiving inadequate dilution from low river flows. A representation of the improvements in water quality downstream of the research area following removal of the Albany Road combined sewer overflows, and remediation of identified intermittent sewage and trade effluent discharges in associated drainage systems, is given in Figure 3.4. The biological results for upstream and downstream of the City (Figures 3.5 and 3.6) show an improvement in the numbers for each species but do not show a significant increase in the diversity at each site. This may be due to the physical restrictions and 'flashy' flow regime in the culverted watercourse.

Figure 3.3 GQA sampling points in the River Sowe catchment



Sample Locations

1. Pickford Brook Holyhead Rd.	SP 307802	2. R.Sherbourne Kingsbury Rd.	SP 309802
3. R.Sherbourne Rudge Rd.	SP 327788	4. R.Sherbourne Charterhouse	SP 344783
5. Hall Brook Manor Farm	SP 318835	6. Hall Brook R.Sowe confluence	SP 347833
7. R.Sowe Astley Lane Bedworth	SP 331870	8. R.Sowe School Lane Exhall	SP 344853
9. R.Sowe DS Hall Brook conf.	SP 348832	10. R.Sowe Tackford Bridge	SP361818
11. R.Sowe Binley Rd Bridge	SP 369785	12. R.Sowe A45 Road Bridge	SP 346756
13. R.Sowe Baginton Mill	SP 338752	14. R.Sowe Stoneleigh	SP 332728
15. Finham Brook Common Lane	SP 300729	16. Finham Brook Finham Bridge	SP 331740
17. Canley Brook S. Henry Pks	SP 308778	18. Canley brook Coventry Rd.	SP 299737
19. Withy Brook High Bridge	SP 387807	20. Smite Brook DS Monks Kirby	SP 464829
21. Smite Brook B4029 Road Br.	SP 422804	22. Smite Brook Coombe Abbey	SP 408804
23. Smite Brook confluence with R.Sowe	SP380795		

Table 3.1 GQA Results for the River Sowe and River Sherbourne 1995-2002

Watercourse	Site	1995		1998		2000		2001		2002		Comments
		chemical	biological	chemical	biological	chemical	biological	chemical	biological	chemical	biological	
Pickford Brook	Holyhead Road	C	D	D	E	C	C	D	Not available	E	Not available	US of R.Sherbourne
R.Sherbourne	Kingsbury Rd	C	D	E	-	B	D	C	Not available	C	Not available	No bio impact
R.Sherbourne	Rudge Rd	D	D	D	-	B	E	B	Not available	B	Not available	US of city centre
R.Sherbourne	Charterhouse	D	E	D	E	B	E	B	Not available	B	Not available	DS of city centre
Hall Brook	Manor Farm	E	D	E	D	E	D	D	Not available	D	Not available	
Hall Brook	Confluence R.Sowe	D	O	C	-	C	-	C	Not available	C	Not available	
R.Sowe	Astley Ln Bedworth	E	E	E	E	C	E	D	Not available	D	Not available	Upper reaches
R.Sowe	School Ln Exhall	C	D	C	-	C	E	C	Not available	B	Not available	US of Coventry
R.Sowe	DS Hall Brook conf.	C	E	C	D	B	D	B	Not available	B	Not available	
R.Sowe	Tackford Bridge	D	E	C	-	B	D	B	Not available	B	Not available	
R.Sowe	Binley Rd Bridge	C	D	C	-	B	C	B	Not available	B	Not available	
R.Sowe	A45 Road Bridge	C	C	C	-	B	E	B	Not available	B	Not available	US R.Sherbourne
R.Sowe	Baginton Mill	C	C	C	C	B	C	B	Not available	B	Not available	US Coventry STW
R.Sowe	Stoneleigh	E	D	E	F	D	C	C	Not available	B	Not available	DS Coventry STW
Finham Brook	Common Lane	B	B	B	C	A	B	A	Not available	B	Not available	To R.Sowe
Finham Brook	Finham Bridge	B	C	B	B	A	B	A	Not available	B	Not available	DS CSOs
Canley Brook	Sir Henry Parkes Rd	C	E	C	E	B	D	B	Not available	B	Not available	Industrial area
Canley Brook	Coventry Road	C	B	B	C	B	D	A	Not available	A	Not available	To R.Sowe
Withy Brook	High Bridge	B	C	B	C	B	B	B	Not available	B	Not available	To R.Sowe
Smite Brook	DS Monks Kirby	C	C	C	C	C	C	C	Not available	C	Not available	DS Monks KirbySTW
Smite Brook	B4029 Road Bridge	B	B	B	-	B	A	B	Not available	B	Not available	
Smite Brook	Coombe Abbey	C	B	C	C	C	C	B	Not available	B	Not available	Fishing lake / algae
Smite Brook	Confl. with R.Sowe	C	C	D	C	D	D	D	Not available	D	Not available	To R.Sowe

Denotes GQA stretches impacted by this investigation

Table 3.2 GQA Results for the River Avon above and below the River Sowe input. 1995-2002

Site	Description	1995		1998		2000		2001		2002		Comments
		chemical	biological	chemical	biological	chemical	biological	chemical	biological	chemical	biological	
R.Avon	A50 Welford	**B**	C	**B**	C	**B**	B	**B**	Not available	**B**	Not available	U/S R.Sowe confluence
R.Avon	Clifton	**B**	B	**C**	B	**B**	C	**B**	Not available	**B**	Not available	U/S R.Sowe confluence
R.Avon	Avon Mill Rugby	**B**	C	**B**	-	**B**	C	**C**	Not available	**C**	Not available	U/S R.Sowe confluence
R.Avon	Newbold	**C**	D	**C**	C	**B**	C	**B**	Not available	**B**	Not available	U/S R.Sowe confluence
R.Avon	Stare Bridge	**B**	C	**B**	C	**B**	A	**B**	Not available	**B**	Not available	U/S R.Sowe confluence
R.Avon	Stoneleigh park	**D**	C	**E**	C	**D**	C	**C**	Not available	**B**	Not available	D/S R.Sowe confluence
R.Avon	Blackdown	**E**	E	**E**	D	**D**	D	**C**	Not available	**B**	Not available	D/S R.Sowe confluence
R.Avon	Leafields	**D**	C	**C**	C	**C**	C	**B**	Not available	**B**	Not available	D/S R.Sowe confluence
R.Avon	Barford	**C**	C	**C**	C	**C**	C	**B**	Not available	**B**	Not available	D/S R.Sowe confluence

The drainage from the River Sowe catchment enters the River Avon above Stoneleigh Park as indicated by ═══ line on Table

☐ Denotes GQA stretches impacted by this investigation

The 2 main watercourses in Coventry were once highly polluted by effluent discharges from major motor manufacturers and their suppliers, via direct discharges, misconnections to surface water sewers, and foul sewer overflows. Their water quality has improved considerably through pollution prevention, enforcement and education as shown in Table 4.2 (Chapter 4). Of the 21 GQA stretches in the City, 76% have improved in quality (16 sites) since 1996 (Environment Agency, 2002), with 2 stretches falling in quality due to algal problems, and 2 stretches remaining the same. Over 60% of classified watercourses in Coventry were assessed as 'fairly good' or class C in the 2000 water quality report (Environment Agency, 2000), and it should not be unreasonable that this level of quality is achieved in the large number of minor culverted watercourses and surface water drainage systems. In the GQA programme of monitoring, a Class C watercourse would be expected to achieve the minimum quality standards as shown in Table 2.7, over a 3-year rolling period of approximately 36 spot samples (Section 2.4.2).

Figure 3.4 Water Quality Improvements in the study area over time (Environment Agency data, 1995-2002)

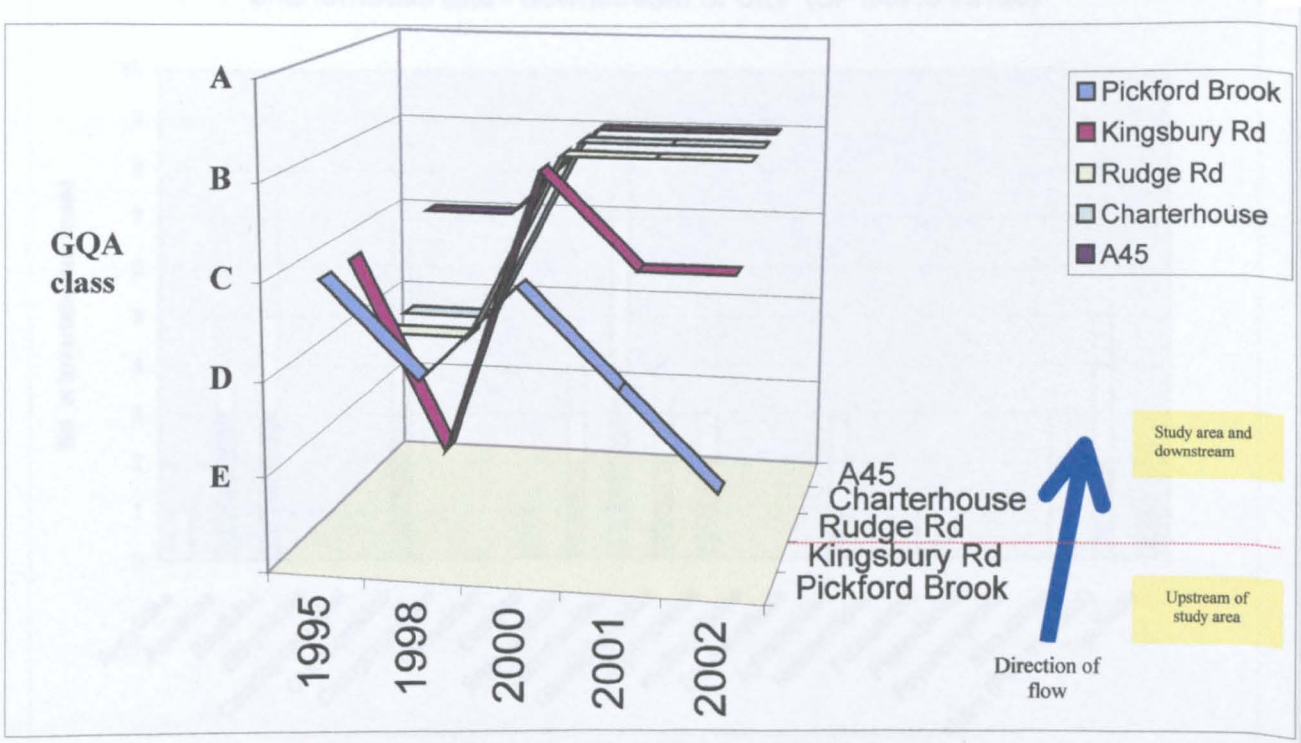


Figure 3.5 Biological Quality River Sherbourne at Spon End (Upstream of City) 1999-2000 (Environment Agency data)

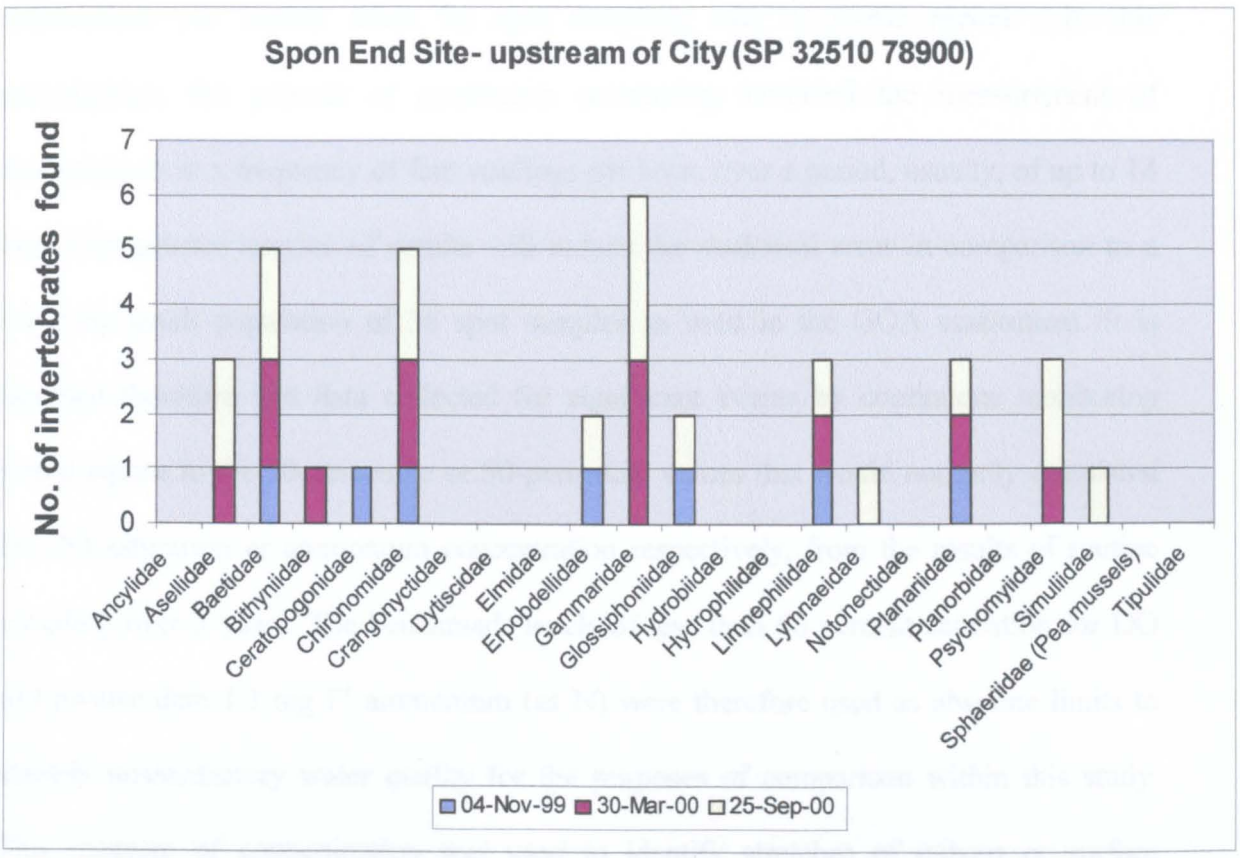
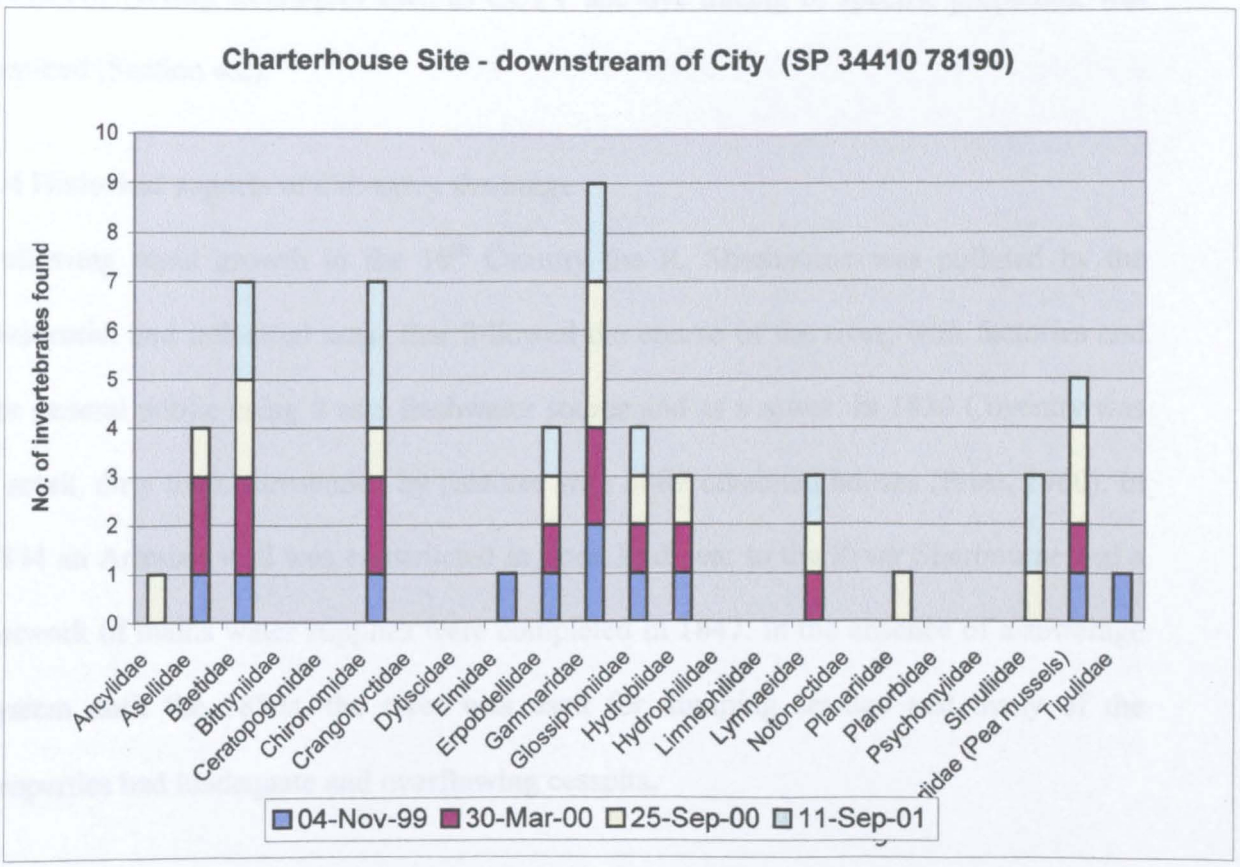


Figure 3.6 Biological Quality River Sherbourne at Charterhouse (Downstream of City) 1999-2001 (Environment Agency data)



The General Quality Assessment standards relate to percentile values obtained from 12 observations per annum taken by spot sampling over a 3-year period. In this investigation, the process of continuous monitoring involved the measurement of determinands at a frequency of four readings per hour, over a period, usually, of up to 14 days. The greater number of results will reduce the statistical error in comparison to a relatively small population of 36 spot samples as used in the GQA assessment. It is assumed therefore that data collected for significant events by continuous monitoring would equate to the 10-percentile or 90-percentile values that would normally calculated for DO saturation or ammonium concentration respectively, from the results of routine sampling over 3 years. The benchmark levels of less than 60 percent saturation for DO and greater than 1.3 mg l^{-1} ammonium (as N) were therefore used as absolute limits to identify unsatisfactory water quality for the purposes of comparison within this study. This measure of contamination was used to identify stretches of culvert or surface drainage system where detailed investigation by further monitoring, or by physical (intrusive) tracing techniques such as CCTV and dye tracing of specific properties, was required (Section 4.2).

3.4 Historical aspects of Coventry drainage

Following rapid growth in the 19th Century the R. Sherbourne was polluted by the residential and industrial areas that followed the course of the river, with factories and the general public using it as a freshwater source and as a sewer. In 1830 Coventry was a small, dirty town surrounded by pastures with 5887 inhabited houses (Prest, 1960). In 1844 an Artesian well was constructed in Spon End near to the River Sherbourne and a network of mains water supplies were completed in 1847. In the absence of a sewerage system until the 1850s, the river was used for dumping sewage and many of the properties had inadequate and overflowing cesspits.

A sewer followed provision of a water supply after Coventry formed a Local Board of Health, which met for the first time in August 1849. The following year the Ordnance survey mapped the area and plans were made for an arterial system of sewers to serve every street in the town. By the mid 1850s, a full time Inspector for the Coventry Board of Health was appointed, and as a result of his work and the provision of sewerage to the town, the death rate fell from 27 per thousand to 23 per thousand in just a few years (Prest, 1960). The Whitley sewage works was also established at this time, but by the 1890s the works was seriously overstretched, and between 1890 and 1900 several thousand pounds were paid in damages and costs by Coventry Corporation as the effluent became worse, polluting the River Sherbourne, and, in turn, the River Sowe and River Avon (Smith, 1946).

A new and larger sewage works was required which could be reached by gravitation, and after several aborted attempts, a number of local inquiries, and even more writs served upon the corporation, a sewage farm was constructed at Baginton, with sewage first applied to the land in 1901. The Ordnance Survey map for Coventry dated 1905 (A. Godfrey, 1996) shows a cattle market situated over the river, and the Corporation stables, silk and cotton mills and the many early cycle and motor cycle factories nestling in the river corridor along with the Public Swimming baths and Abattoir. The river at this time was open along its length, and whilst the water was probably used for supplying process water to the sites, it was undoubtedly used for trade effluent disposal as well. The rapid rise in the population of Coventry, and the requirement to include the treatment of trade effluents, including gas production liquors from the Coventry gas works site at Gas Street/ Abbots Lane, soon meant that the River Sowe was again suffering from the effects of poor effluent discharged from the inadequacy of treatment by the sewage farm. A replacement sewage treatment plant was constructed in around

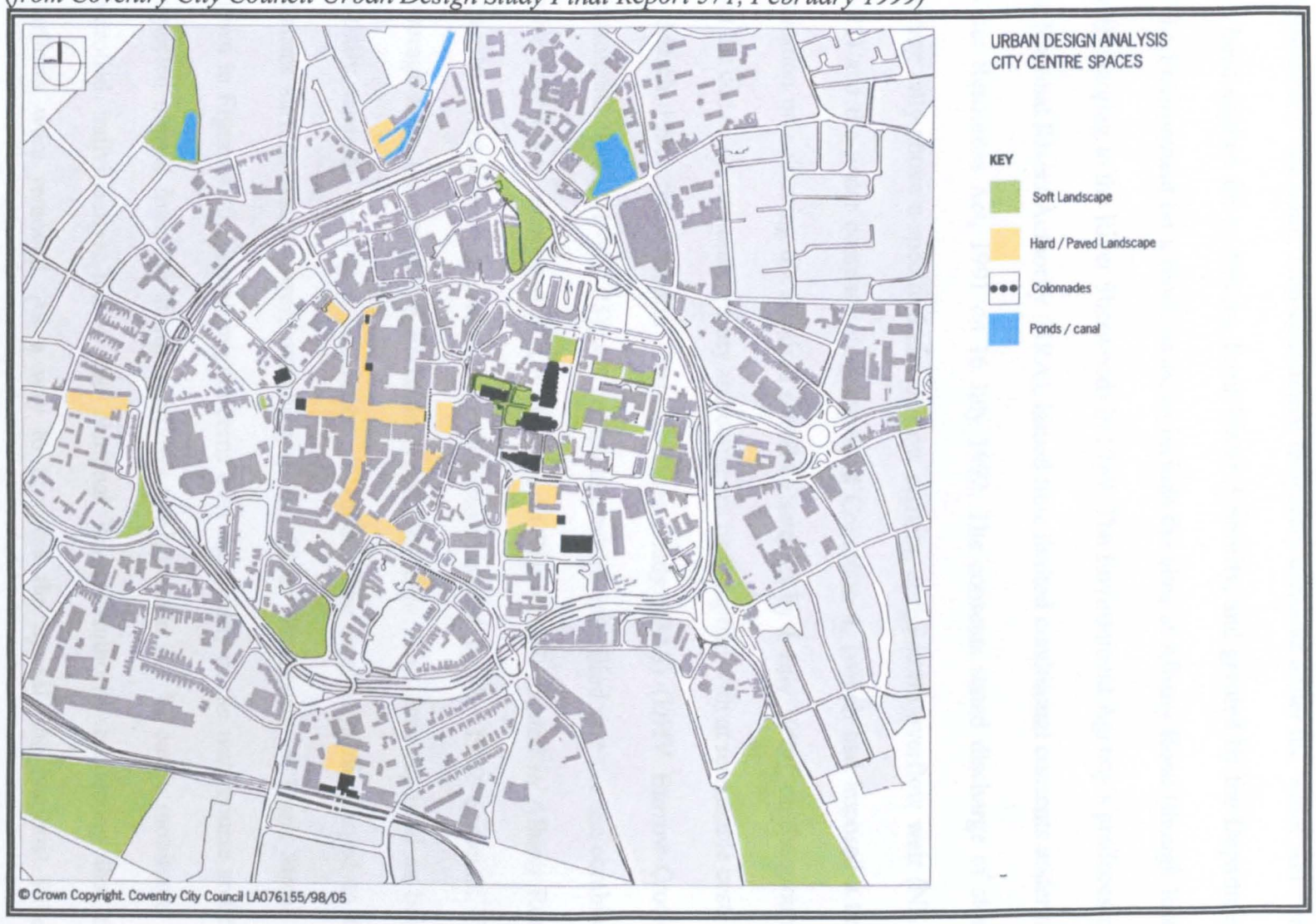
1934, at Finham, on the outskirts of Coventry as shown in Figure 1.1. Though post-war increases in the population of Coventry and the manufacturing growth which gave rise to increased trade effluent production has led to a number of additions to the Sewage treatment works at Finham in Coventry, the requirement became focused on improved effluent quality rather than increased treatment capacity, and a demand for minimal environmental impact on the environment led to an appreciation of the seasonal problems still apparent in the River Avon and a driver for improvement under the AMP (Asset Management Plan) scheme as detailed in Section 3.2.1.

Coventry currently has an inner ring road system and a partially pedestrianised city centre, as shown in figure 3.7, which will become more accessible to pedestrians, (and consequently less accessible to vehicle users) over the next 10 years (Coventry City Council Urban Design Study Final Report 571, February 1999). The importance of impervious areas, and their impact on urban runoff is discussed in Section 2.2.1. Because of the extensive catchment area of urban drainage discharging to the River Sherbourne, it is unlikely that pedestrianisation of the inner city area will significantly reduce the total pollutant load to the watercourse, unless porous surfaces are introduced, and vehicle use in the city is significantly reduced as a result of the development.

3.5 The Historical aspects of the Albany Road Combined Sewer Overflows and early water quality problems

In December 1991 Severn Trent identified the existence of six combined sewer overflows located on Albany Road, as shown in Figure 4.10, requiring conditional Consent to discharge to controlled waters under the newly enacted Water Resources Act, 1991. In 1983 a major capital scheme had provided replacement foul and surface water sewers in the Albany Road area, including a 1125mm diameter sewer to relieve overloading the Albany Road sewer and six overflows on the combined 450mm

Figure 3.7: Urban Design Analysis Coventry City Centre Spaces
(from Coventry City Council Urban Design Study Final Report 571, February 1999)



diameter sewer, discharging to the adjacent surface water sewer to outfall to the River Sherbourne at one point. Non-conditional temporary consents under the Water Act 1989 had been applied for by Severn Trent Water Authority, and granted by the Department of the Environment on a block basis, to include the sites at Albany Road (though listed as discharging to the River Sherwood) in 1989. The Environment Agency's predecessor, the National Rivers Authority (NRA), issued time limited conditional consents under the Water Resources Act, 1991 on 16 July 1992. The consents stated discharge of storm sewage only above a specified rate of flow arriving at the storm overflow weir (NRA, 1991) and the water company duly appealed Condition 4, (which had imposed a time limitation on achieving the required overflow settings by 1 July 1995), on the grounds that the condition was unnecessary and could not be complied with at reasonable cost.

In March 1993, the Earlsdon Drainage Area Study (DAS) (DHV Burrow-Crocker Consultants, 1993) (L-921-05) was completed, which identified that the six combined sewer overflows, referenced SOL-921-05-01 to SOL-05-07, located in Albany Road, Coventry were operating under the conditions required by the 1992 consents. The sewerage area, known as the Earlsdon North Drainage Area, was reported as being partially separate, serving a population of 16000. The overflows discharged to the adjacent surface water sewer, outfalling to the River Sherbourne at Hope Street as shown in Figure 4.10. Continuing concerns over the quality of the watercourse and the suspected impact from the storm overflows (which could not be easily monitored or controlled individually), led to the National Rivers Authority requesting that the overflows were removed. As a way to progress the appeal, the National Rivers Authority reviewed the consents in November 1994, but maintained that the proposed conditions were correct, and in addition, requested the provision of debris screening on all storm overflows.

General Quality Assessment results in 1995 identified a failing stretch of watercourse for the River Sherbourne between Queen Victoria Road, at the top end of the culverted section, and the confluence with the River Sowe. The sample point for this assessment was at the bottom end of the culvert at Charterhouse. The River Quality objective at this point was class C, but the chemical quality was recorded as class D, with the Biological quality denoted as class E. The stretch of the River Sherbourne above this (from Kingsbury Road on the outskirts of Coventry and Queen Victoria Road) was also considered as a failing watercourse at class D. This stretch was sampled downstream of the Hope Street outfall. Visual inspection of the river identified sewage debris at the outfall and along the banks of the river, and it was suspected that the Albany Road sewer overflows were unsatisfactory, and having a major impact on the watercourse downstream of the culvert. The routine spot sampling did not reflect this in terms of ammonium concentration sampled, but Biochemical Oxygen Demand (BOD) results within the routine monthly sampling programme at Rudge Road were as given in Table 3.3:

Table 3.3 Biochemical Oxygen Demand during early monitoring at Rudge Road (*National River Authority, 1995*)

Date	BOD (mg l^{-1})
05/01/93	7.0
02/09/93	>19
01/09/94	8.0
27/04/95	6.0

The 1995 water quality report (NRA, 1995) gave a 90-percentile figure of 6.39 mg l^{-1} for BOD at Rudge Road. The figures for Charterhouse were also poor with a BOD 90-percentile concentration of 6.3 mg l^{-1}. The individual monitoring results for Charterhouse, are reported in Table 3.4:

Table 3.4 Biochemical Oxygen Demand Values during early monitoring at Charterhouse (*National River Authority, 1995*)

Date	BOD (mg l^{-1})
05/01/93	13.0
01/09/94	9.0
04/01/95	>16.0

In 1996 one of the overflows was closed, and although the River Sherbourne was out of class, the overflows did not feature in the priority list for the Asset Management Plan 1995-2000 (AMP3). Time limited consents issued by the National Rivers Authority expired in July 1995. In 1996 the Water Company applied for five new consents. Water quality monitors were installed in the watercourse in late 1996 and early 1997, as discussed in Section 4.4.1, to assess what impact the overflows were having, and the results are given in Section 5.2. The surveys showed peaks in ammonia of >5 mg l^{-1} downstream of the outfall, against values of less than 1.5 mg l^{-1} upstream, and Dissolved Oxygen sags immediately downstream resulting in <20% saturation, with 0% saturation recorded at Charterhouse 3 km away. Complaints from residents in the vicinity of the outfall and downstream river continued, reporting smells of sewage following significant storm events. The Environment Agency commissioned a detailed review of the Earlsdon DAS in late 1996, following an application by the Water Company for permanent discharge consents, and concluded that the figures arrived at in the DAS, and submitted in the applications, had errors. The applications were consequently resubmitted correctly.

As a result of the water quality investigations, the Environment Agency concluded that the overflows were unsatisfactory as defined in the consenting manual (NRA, 1991), and gave time limited consents lasting only until 31 March 2000, so that they could be placed on the Asset Management Plan 2000-2005 (AMP3) high priority list for removal

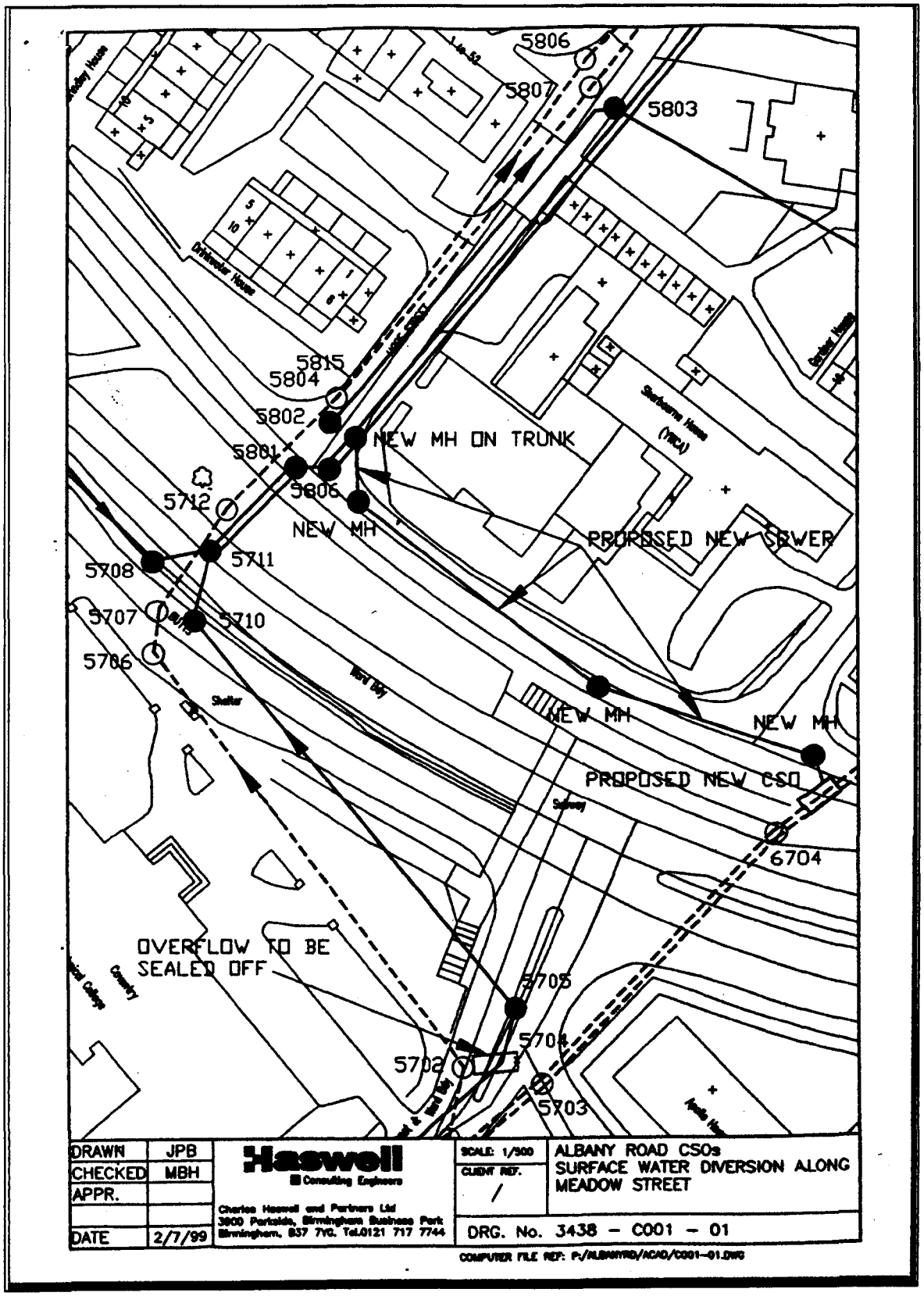
or replacement. In light of this decision, the evidence produced, and the availability of 'extra spend' money available under AMP3, the scheme to remove the storm overflows was proposed by the Environment Agency and approved by Severn Trent Water Ltd. by December 1997, with a proposed completion date of March 2000. In the General Quality Assessment of 1998 (Environment Agency, 1998) conditions at the Rudge Road site improved to class C, but the GQA assessment site at Charterhouse remained at class D with biological quality reported as class E. At Charterhouse a 90-percentile BOD concentration of 6.53 mg l^{-1} was recorded, and complaints relating to smell nuisance and sewage debris continued. It was not known whether the failing watercourse was affected by domestic misconnections, leaking sewers, illegal industrial effluents or the unsatisfactory operation of legal, permitted, sewage overflows located in the vicinity. The fact that the biological quality of the river at Charterhouse, below the City, was very poor, and was not represented in the reported chemical quality at the site, indicated an intermittent problem that had not generally been identified in the monthly spot sampling method employed by the Environment Agency. In early 1999 the Water Company suggested that removal of all of the overflows was not cost effective, and suggested that the complex scheme would not be completed in March 2000. The Environment Agency extended the period of consent on all of the storm overflows to September 2000, but would not relent further on extending the implementation of a scheme to improve the situation. It was still considered that all, or some, of the five remaining CSOs located at Albany Road were unsatisfactory, and it was suspected that one or more of the culverted watercourses draining to the culverted River Sherbourne were also contaminated. Strong evidence was required to address the problem with the sewerage undertaker; to investigate operating conditions of the combined sewer overflows further, and address

any unknown combined sewer overflows or leaking foul drainage systems elsewhere in the City.

Although the GQA failures identified above related to analysis of Biochemical Oxygen Demand (not ammonia concentration, which at the time did not have an identified acceptance level for the River Sherbourne), sampling or continuous monitoring for Biochemical Oxygen Demand was not viable in terms of cost or practicality.

Identifying features of sewage contamination were well known (Klein, 1972; UPM FR/CL 0002, 1994), and it was decided to monitor ammonium levels, specific conductivity, dissolved oxygen and pH, to investigate whether sewage or industrial discharges were impacting upon the water quality of the watercourse. The monitoring data collected was presented to Severn Trent Water Limited and the Regional Water Quality department of the Environment Agency, and a submission under the Asset Management Programme was eventually agreed. A scheme to replace the combined sewer overflows with one high level overflow, and the use of an adjacent storm sewer as an additional foul sewer, was eventually proposed and agreed, as shown in Figure 3.8. The increased flow carried on for full treatment would add to the problems experienced with storm overflow spillage at Finham Sewage treatment Works, but this additional volume was incorporated into the calculations for the proposed development at the site as discussed in Section 3.7.

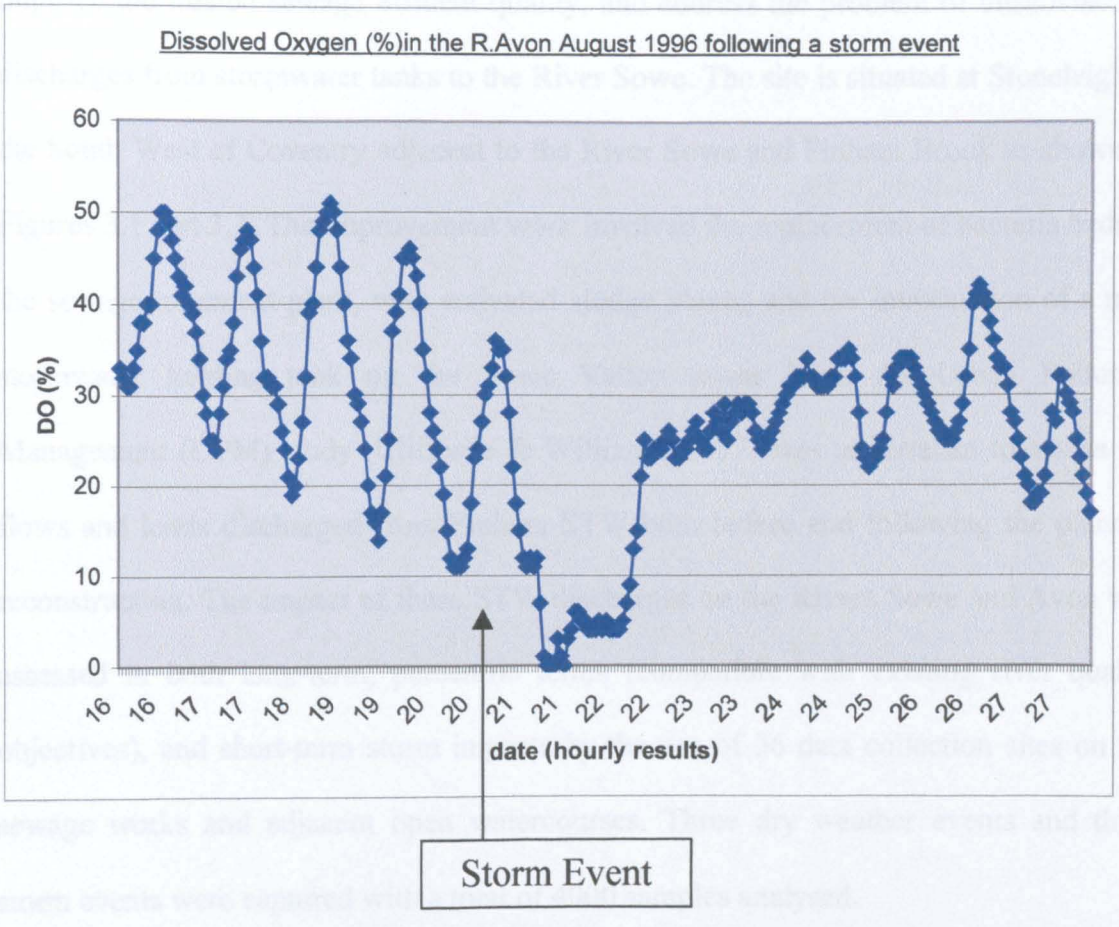
Figure 3.8. Proposed remediation scheme for Albany Road CSOs. (Haswell, 1979)



3.6 Seasonal problems in the Sowe and Avon Catchments

During the 1990s, until the recent refurbishment of Coventry Sewage Treatment Works, DO levels were reduced to below 10% saturation following summer storms, particularly after a spell of hot, dry weather. In the summer of 1994, oxygen levels fell to 11% saturation (1 mg l^{-1}) at Saxon Mill and several hundred fish died as a result. The remaining fish were rescued for removal to private pools, and the water was aerated at strategic points along the river. Each year during July and August the River Avon was monitored daily for oxygen depletion, and aeration equipment deployed as a precautionary measure following storms. On 22 August 1996 over 500 fish died as a result of a storm 2 days previously, and saturated oxygen levels fell to a minimum of 0% saturation at Saxon Mill as shown in Figure 3.9;

Figure 3.9 Dissolved Oxygen (percentage saturation) levels in the River Avon at Saxon Mill following a storm event on 20 August 1996 (arrowed) (Environment Agency, 1996)



The oxygen depletion lasted for up to 12 hours, and it was recognised that the combination of sewage effluent discharging at full flow (and maximum consent conditions), allied with otherwise untreated settled storm sewage discharges from the sewage works and the impact of the Coventry City drainage system, had a cumulative effect in polluting the River Avon with a high BOD and high ammonia 'plug' of effluent. In the deep waters of the River Avon above the weir at Saxon Mill this had the effect of producing an oxygen sag, as shown in Figure 2.4 and discussed in Section 2.3.1. The situation required immediate action, and led to the Sowe catchment Urban Pollution Management study (Clifforde & Williams, 1997) discussed in the next section.

3.7 Sowe catchment UPM Methodology

Major reconstruction of the Coventry (Finham) Sewage Treatment Works was progressed within the Asset Management Plan (AMP 2) programme (NRA, 1993) to improve the treated sewage effluent quality, and address the problem of unsatisfactory discharges from stormwater tanks to the River Sowe. The site is situated at Stoneleigh to the South West of Coventry adjacent to the River Sowe and Finham Brook as shown in Figures 3.1 and 3.3. The improvement work involved the replacement of bacteria beds at the sewage treatment plant, with activated sludge plants, and the introduction of a new stormwater holding tank on the Sowe Valley sewer inlet. An Urban Pollution Management (UPM) study (Clifforde & Williams, 1997) was undertaken to assess the flows and loads discharged from Finham STW both before and following the planned reconstruction. The impact of these STW discharges on the Rivers Sowe and Avon was assessed in both long-term, percentile terms (compatible with existing river quality objectives), and short-term storm impacts by the use of 36 data collection sites on the sewage works and adjacent open watercourses. Three dry weather events and three storm events were captured with a total of 4000 samples analysed.

3.8 Sowe catchment UPM Results, Conclusions and Recommendations

The UPM study predicted that modifications in treatment at the sewage treatment works would result in major improvement of watercourses below the effluent outfalls at Stoneleigh (Clifforde & Williams, 1997). Modelling results indicated that annual loads of all of the major pollutants were reduced: Biochemical Oxygen Demand was typically reduced by 59%, ammonia by 41% and suspended solids by 10%. Dissolved oxygen levels were generally shown as higher following construction of the new works, and storm events typically start from, and return to, an improved position in this respect.

The results of the UPM study suggested that the sewage works pre-construction contributed more than half of the BOD load in the River Sowe. The prediction for post-construction was that this would, at best, fall to a quarter of the load. The results of 2 storm events monitored during the study on 27 October and 3 December 1996, suggested contribution budgets for BOD, ammonia, and suspended solids that presented a significant input by the River Sowe catchment above the sewage treatment works, as shown in Table 3.5.

The results suggested that further investigation of the upstream contribution was required to understand and improve the problems of low dissolved oxygen and high ammonia concentrations as already discussed in Section 3.6. Chapter 4 explains how the quality of the urban River Sowe catchment (and in particular the River Sherbourne drainage through the City of Coventry), was investigated using conventional spot sampling methods, and by the use of continuous monitors, to determine the contribution of pollutants in the urban river system, to the problems identified downstream in the River Avon.

Table 3.5: Comparison of Inputs from Finham Sewage Treatment Works and other upstream sources. *(modified after Foundation for Water Research, 1998.)*

	Event 27/10/96		Event 3/12/96		Average %
	Load (kg)	**% Total**	**Load (kg)**	**% Total**	
BOD					
STW eff/storm	1239	41	1619	46	43
R.Sowe (u/s)	636	21	760	21	21
Finham Brook	253	8	318	9	9
Total (Sowe d/s)	3014		3547		
AMMONIA					
STW eff/storm	440	114	858	82	88
R.Sowe (u/s)	38	10	73	7	8
Finham Brook	19	5	28	3	4
Total (Sowe d/s)	386		1051		
S.SOLIDS					
STW eff/storm	-	-	1810	4	4
R.Sowe (u/s)	-	-	22194	44	44
Finham Brook	-	-	8221	16	16
Total (Sowe d/s)	-	-	50598		

Key to table:
eff effluent DS downstream STW sewage treatment works
US upstream S. SOLIDS suspended solids

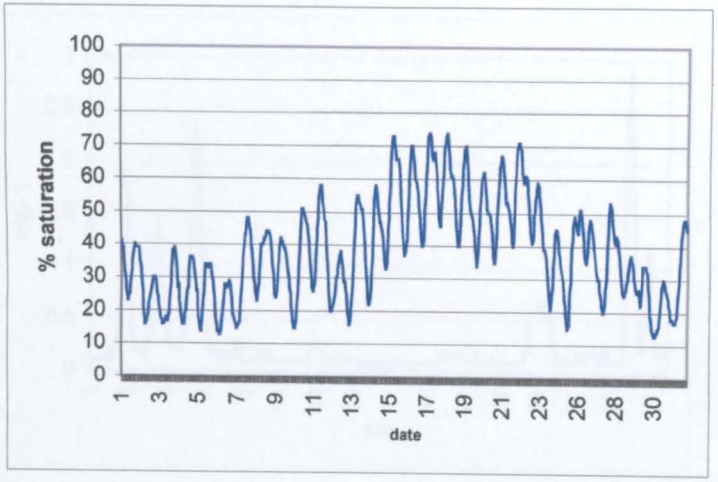
3.9 Water Quality Improvements in The River Avon Catchment

As a result of improvements to Coventry (Finham) Sewage Treatment Works, and the removal of identified continuous and intermittent polluting discharges in the River Sherbourne (and surface water drainage systems) (Chapters 5 and 6), the problem relating to high ammonium concentrations and low DO saturation experienced each year in the River Avon at Saxon Mill (Section 3.6) were diminished. The DO saturation recorded in July each year between 1996 and 2000 increased significantly, and the concentration of $NH_4^+(N)$ decreased. The results are given in Figures 3.10 and 3.11.

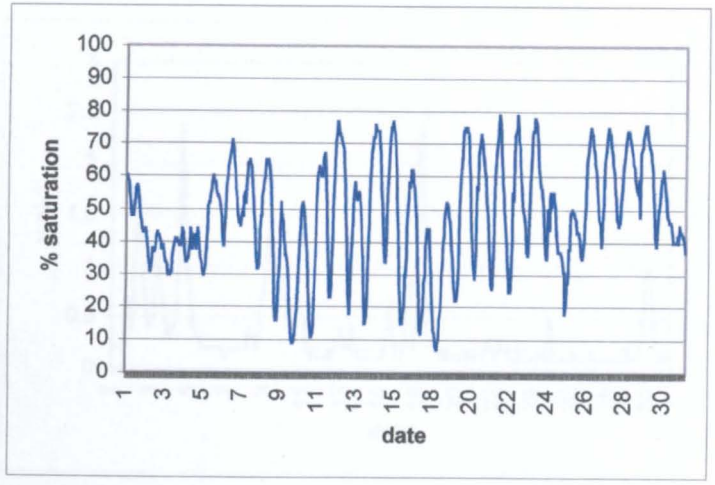
Later results were not available due to the closure and subsequent decommissioning of the water quality monitor at Saxon Mill, as discussed in Section 3.2.

Figure 3.10a)– e) DO % saturation for July in the River Avon 1996-2000.

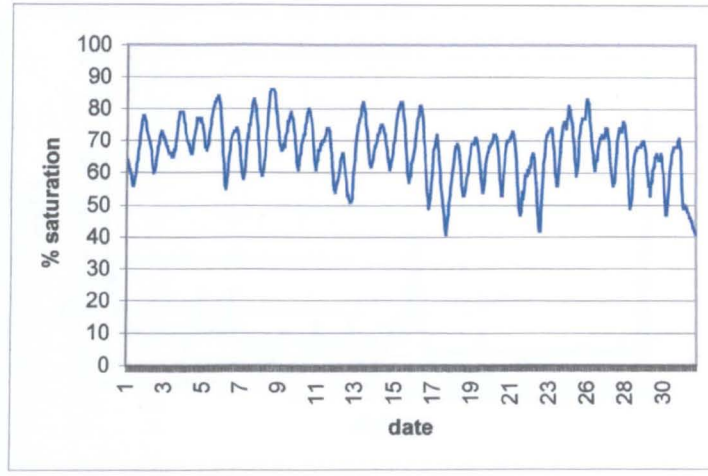
a) 1996



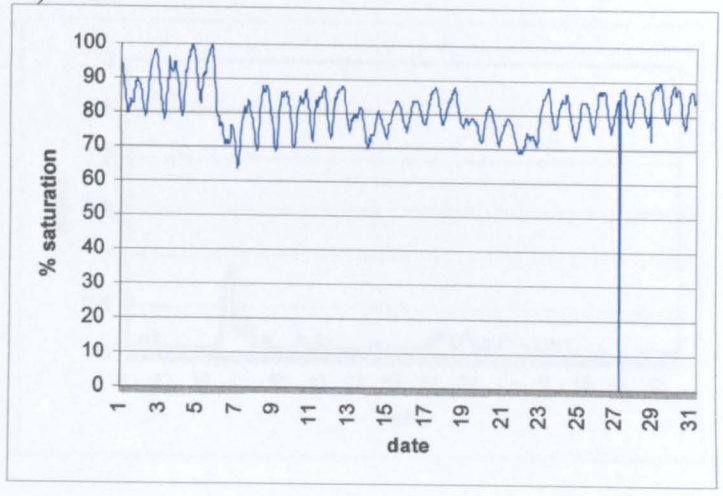
b) 1997



c) 1998



d) 1999



e) 2000

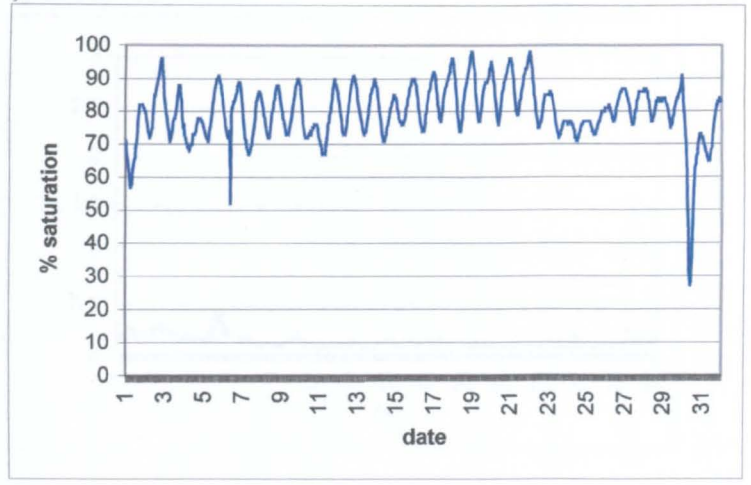
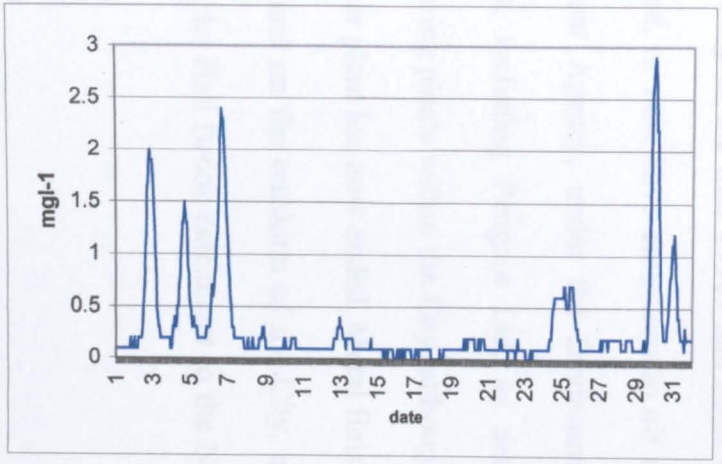
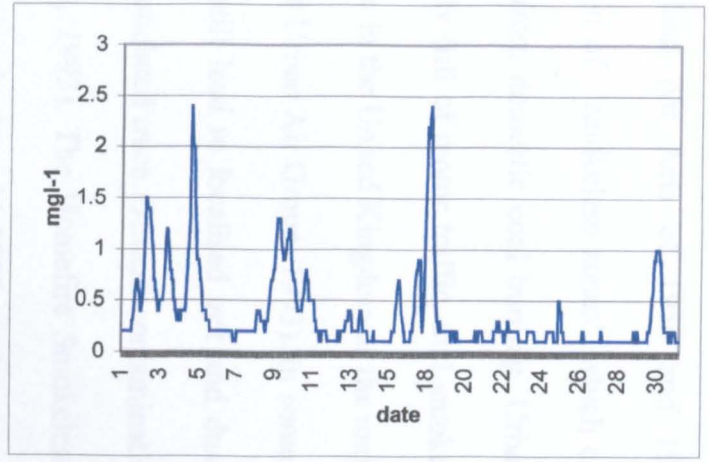


Figure 3.11a)– e) Ammonium concentration (mg l^{-1} NH_4^+(N)) for July in the River Avon 1996-2000.

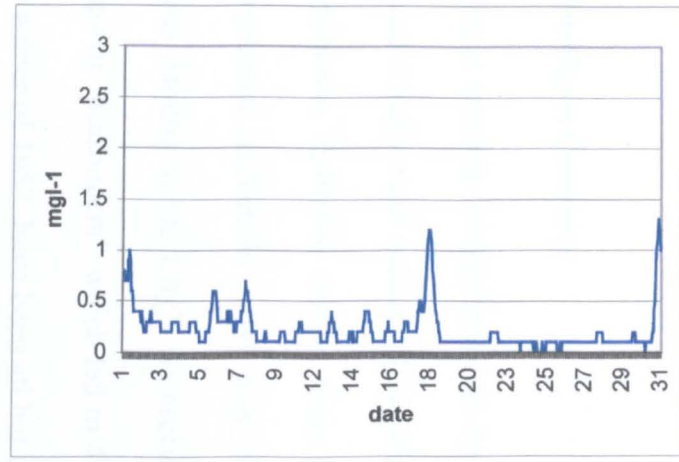
a) 1996



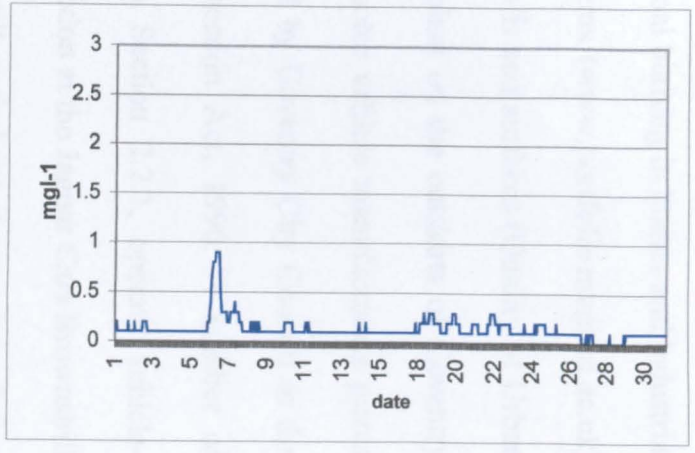
b) 1997



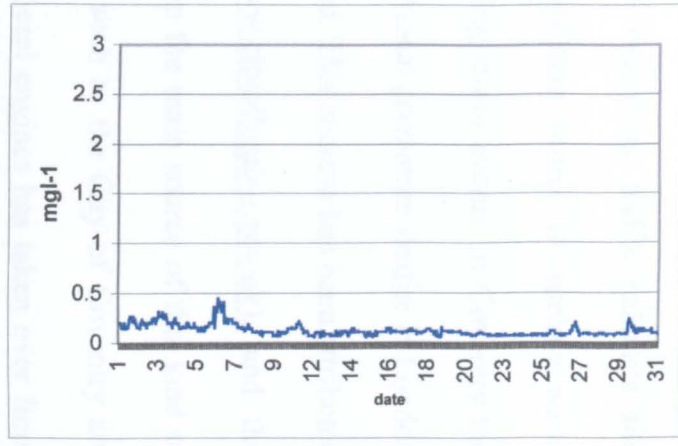
c) 1998



d) 1999



e) 2000

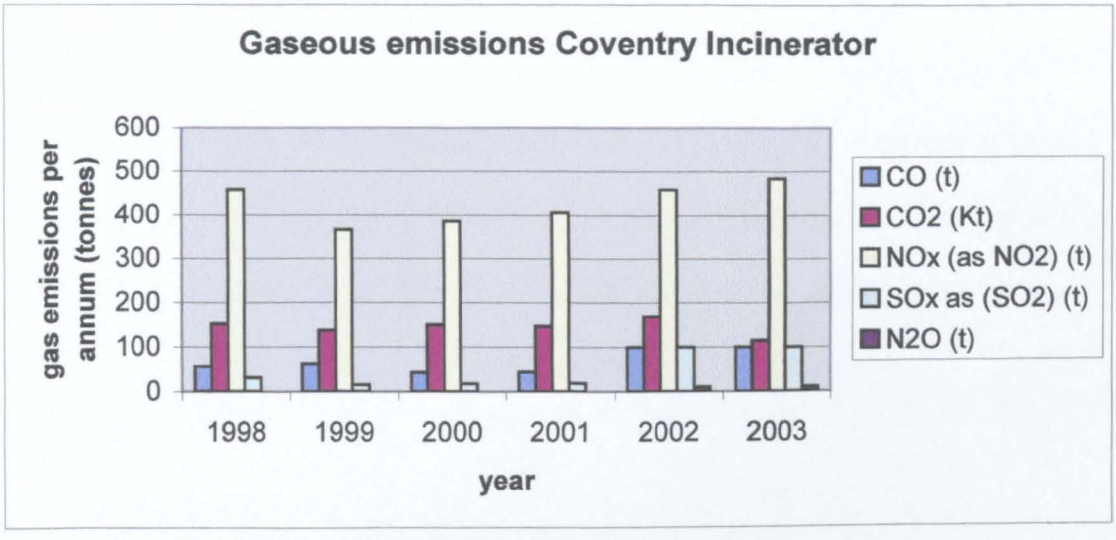


3.10 Air Quality in Coventry

Coventry has a centrally located waste-to-fuel incinerator, a multitude of manufacturing industries and a major road network, (including an inner ring road), in the vicinity of the River Sherbourne. Pollution arising from industrial emissions, traffic exhausts and densely populated residential areas may be an important source of surface water contaminants passing to the City's watercourses during storm events. In Coventry the urban smogs or 'peasoupers', which led to 4000 additional premature deaths in London during the winter of 1952, have been all but eliminated. This success has been attributed to the Clean Air Acts of 1956 and 1968 (www.cityoflondon.gov.uk), and the introduction of 'smokeless zones', which cleaned up the main source of this kind of pollution from domestic coal burning. Urban areas such as the City of Coventry are increasingly full of motor traffic, and smoke from diesel engines has taken over from coal smoke in the United Kingdom as the major cause of blackening of building surfaces (Quality of Urban Air Group, 1993). In some areas coal burning in homes and industrial activities still lead to localised grit and dust problems (www.portfolio.mvm.ed.ac.uk) and the associated trace element contamination of soils and surfaces (Quality of Urban Air Group, 1993). The Homefire Smokeless Fuel plant on the outskirts of Coventry ceased trading in the mid 1990s and most of the motor vehicle manufacturing plants have closed, or now have emissions to air regulated by Coventry City Council or the Environment Agency, under the Environment Protection Act, 1990. A number of companies, including Peugeot Ltd, as detailed in Section 2.2.3, operate vehicle-manufacturing plants within the City, although production at the Jaguar Cars Brownshill Lane Jaguar plant has now ended. Metal finishing is still carried out at a number of sites centrally, and on the outskirts of the City, and there is one small aluminium foundry located in the Hall Brook catchment to the North of Coventry. The largest point source

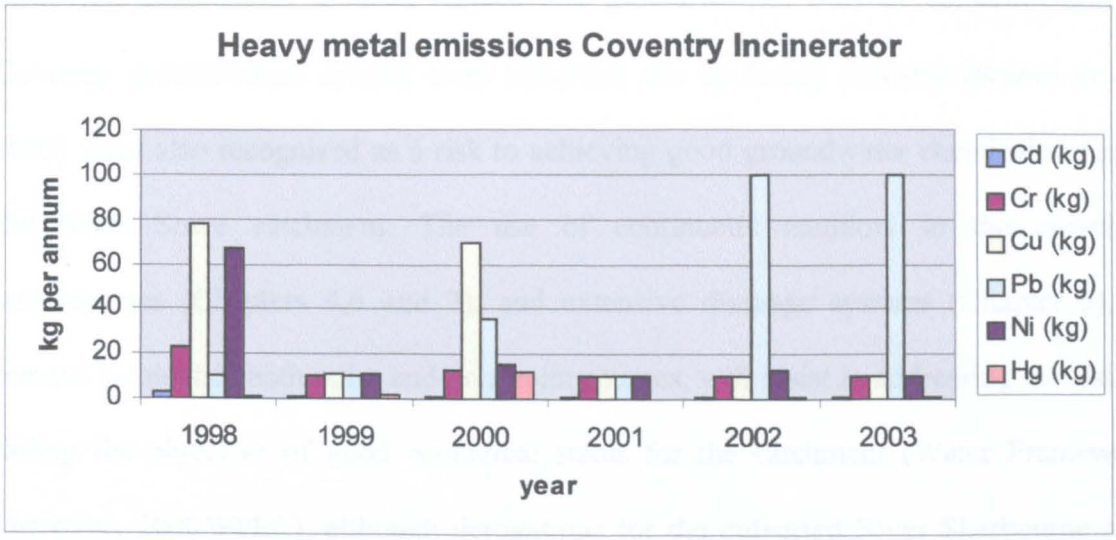
of pollutants in the centre of Coventry is the 'waste to energy' incinerator situated at Bar Road, adjacent to the River Sherbourne. The incinerator plant does not have any consented discharges to the River Sherbourne, but treated emissions to the air are controlled by a permit issued by the Environment Agency under the Pollution Prevention and Control Regulations (Pollution Prevention and Control (England and Wales) Regulations 2000 SI 1973), as required by the Integrated Pollution Prevention and Control Directive (IPPC 96/61/EC). The annual gaseous emission rates from this incinerator are published by the Environment Agency on their web site (www.environment-agency.gov.uk), and are summarised in Figure 3.12:

Figure 3.12 Annual gaseous emissions from Coventry incinerator (data from Environment Agency web site – Pollution Inventory)



The results for heavy metals emissions from Coventry Incinerator, published as annual loadings (kg annum^{-1}) in the Pollution Inventory on the Environment Agency website (www.environment-agency.gov.uk) are shown in Figure 3.13.

Figure 3.13 Annual heavy metal emissions from Coventry Incinerator (data from Environment Agency web site – Pollution Inventory)



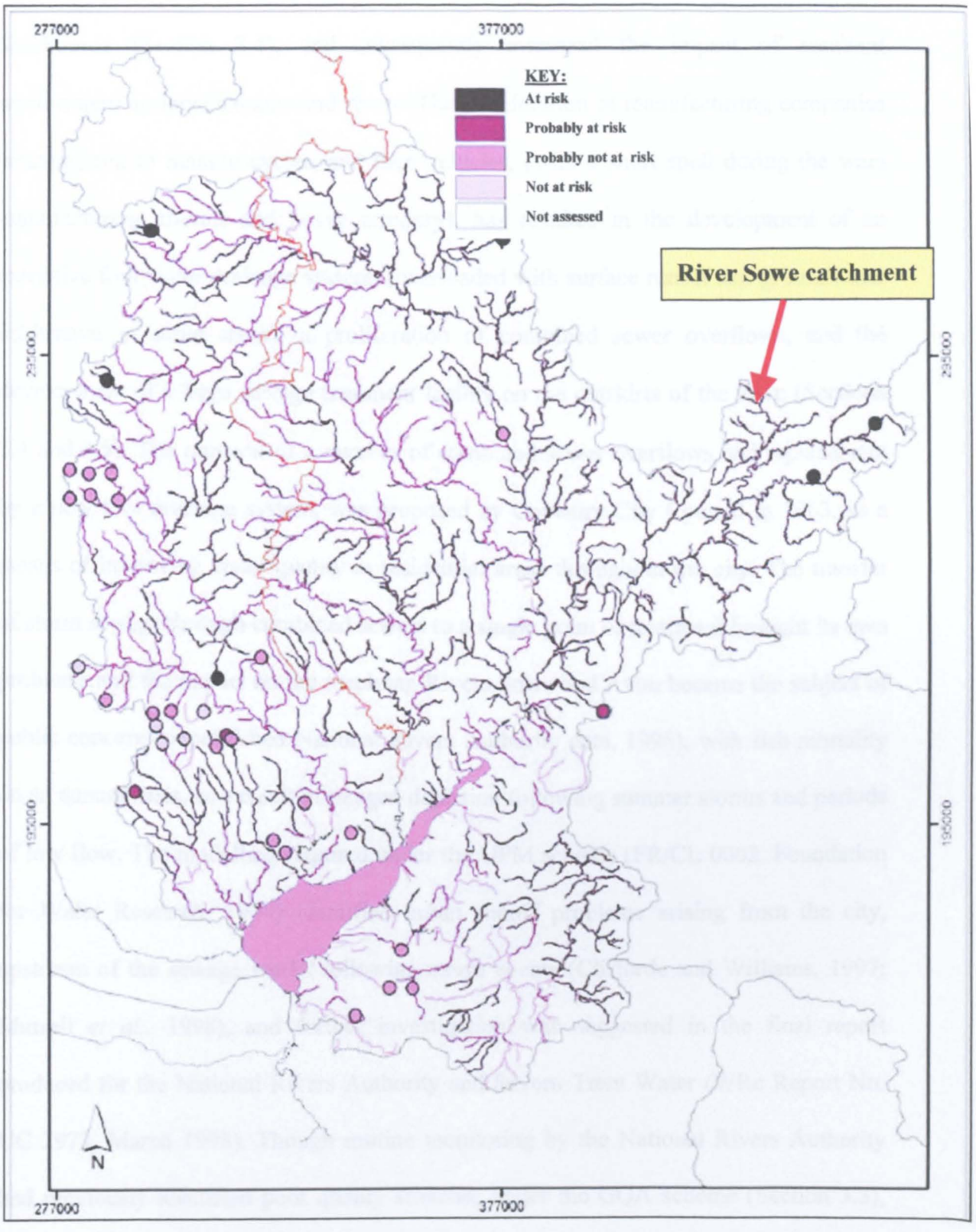
The presence of metals in the atmosphere arising from the Coventry incinerator may be a factor in total metal concentrations found in some water quality spot samples, taken in the City over a number of years. Samples taken in this research from the River Sherbourne after remediation of the organic contamination sources, included analysis for total metals to determine whether metal concentrations were unusually high for an urban watercourse (based on reference to previous studies), and to identify the nature and possible sources of any heavy metals identified in the city centre culvert.

3.11 Water Framework Directive – environmental pressures in the R.Sowe catchment.

The main pressures identified for the Lower Severn area during the initial characterization of waterbodies by the Environment Agency (Section 2.6.1) are (in descending order of importance), non-point sources (as shown in Figure 3.14), alien species, nutrients from agriculture, morphological impacts arising from flood defence and urbanisation, and failure of sanitary determinands such as BOD, DO and NH_3N (see Section 2.3). In the River Sowe catchment, urban runoff, sanitary determinand failure and non-point sources of N and P were identified as significant pressures by the

Environment Agency using national datasets (Environment Agency, 2004) against achieving good status in both surface and groundwaters. Solvent contamination of Coventry groundwaters arising from historical use by heavy industry (Nazari *et al.*, 1993) were also recognized as a risk to achieving good groundwater chemical status in the River Sowe catchment. The use of continuous monitors in the culverted watercourses (Chapters 4,6 and 7), and extensive drainage systems (Chapter 5), to remove or identify both point and non-point sources, will assist in addressing the risk of failing the objective of good ecological status for the catchment (Water Framework Directive, 2000/60/EC), although derogations for the culverted River Sherbourne as a heavily modified watercourse could apply.

Figure 3.14 Risk Assessment for Pressure from non-point sources on surface waters in the Lower Severn Area (Environment Agency (not published), 2004)



3.12 Conclusions

The population of Coventry has expanded rapidly around the Rivers Sowe and Sherbourne (Section 3.4), and subsequently increased the impact of resultant wastewaters on local streams and rivers. The proliferation of manufacturing companies weaving silk to making cycles, and then vehicles, (with a short spell during the wars manufacturing aircraft and heavy armoury), has resulted in the development of an extensive foul water drainage system, (overloaded with surface runoff and groundwater infiltration in some areas), a proliferation of combined sewer overflows, and the development of a large sewage treatment facility on the outskirts of the town (Sections 3.4 and 3.5). The removal of a number of combined sewer overflows and replacement by a new foul drainage system, was proposed by Coventry City Council in 1963, as a means of improving water quality in residential areas throughout the city. The transfer of storm sewage through combined sewers to a single point of treatment brought its own problems and the impact on the receiving Rivers Sowe and Avon became the subject of public concern (unpublished National Rivers Authority data, 1996), with fish mortality on an annual basis, as a result of oxygen depletion following summer storms and periods of low flow. The modelling required under the UPM scheme (FR/CL 0002. Foundation for Water Research, 1994) identified urban runoff problems arising from the city, upstream of the sewage works following storm events (Clifforde and Williams, 1997; Murrell *et al.,* 1998), and further investigation was suggested in the final report produced for the National Rivers Authority and Severn Trent Water (WRc Report No. UC 2973, March 1998). Though routine monitoring by the National Rivers Authority had previously identified poor quality stretches under the GQA scheme (Section 3.3), they did not identify the diffuse, intermittent and illegal sources giving rise to the deterioration in quality; hidden in the extensive surface water drainage system and

culverted watercourses. This research investigated the sources of urban pollution arising in these systems during dry periods and during storm events. An historical assessment of the impact and legal aspects of the overflows was undertaken with reference to water quality issues identified at the time (Section 3.5), and a period of monitoring the culverted River Sherbourne upstream and downstream of the Albany Road combined sewer overflows was instigated (results given in Chapters 6 and 7). The methodology for investigating the impact of these overflows and the use of continuous monitors to determine the nature and location of previously unidentified illegal and intermittent discharges to the surface drainage system is detailed in Chapter 4.

The contribution of particulates to street dusts and sediments, and the potential for transport in watercourses, was discussed in Chapter 2 (Section 2.2.2). The emission results for Coventry incinerator (www.environment-agency.gov.uk), which is situated within the catchment of the River Sherbourne, are given in Section 3.10. The potential for these emissions to contribute to the runoff of pollutants is determined in Chapters 6 and 7 and is discussed in Chapter 8.

The information gathered from this research was used, in accordance with the aims and objectives given in Chapter 1, to justify the removal of unsatisfactory storm overflows, locate the exact discharge point of unknown illegal pollution sources, and determine whether the resultant water quality requires further improvement, to meet water quality standards for current and future uses of the Rivers Sherbourne, Sowe and Avon. As discussed in Section 3.11, this information will assist the Environment Agency in tackling the pressures associated with urban runoff, sanitary determinand failure and non-point source pollution identified in the preliminary characterisation of risks to water bodies, as required under the Water Framework Directive (2000/60/EC).

Chapter 4. Urban runoff in the River Sowe catchment.

Introduction

Chapter 3 described the historical factors leading to a serious deoxygenation problem in the River Avon downstream of the Coventry drainage area, and identified that further monitoring was necessary to identify the unknown sources of pollutants, both continuous and intermittent, leading to poor water quality in the area. This chapter describes how watercourses were prioritised for continuous monitoring, and how the technology was used in surface water drainage systems and culverted watercourses to identify illegal discharges, in an effective and efficient manner. Section 4.1 considers reductions in spot sampling for routine GQA assessment by the Environment Agency, and Section 4.2 suggests an alternative methodology for investigating water quality in urban watercourses, using continuous water quality monitors during storm events and in dry weather, and for their utilisation in confined drainage systems. The methodology will define how three phases of investigation were used to satisfy the five objectives outlined in Chapter 1, and identify the practical difficulties, successes and limitations of the monitoring equipment used, as described in Sections 4.2.1 and 4.6. The chapter outlines monitoring locations and Health and Safety considerations for utilisation of the continuous water quality monitors, and automatic samplers, and identifies the range of parameters used to investigate the pollutants arising from urban runoff in the targeted areas.

4.1 Problems previously identified in the River Sowe catchment – the way forward.

Reports to the Regulatory bodies regarding pollution incidents in Coventry have, since records began, involved chemical spillages, leaking oil tanks, fires, illegal trade effluent discharges, visible sewage debris, discoloured water and river beds, algal blooms and dead fish. This information identified that the culverted watercourses and surface water

systems in the area were prone to polluting discharges arising from poor pollution prevention measures, illegal discharges and antiquated drainage systems and misconnections. As a result of the large number of reported pollution investigations in the city, the requirement to control trade effluent discharges and maintenance of the sewerage assets, the surface water, combined and foul sewerage systems in Coventry have been extensively mapped and improved by the Severn Trent Water Ltd and it's sewerage agents, Coventry City Council. With the construction of a single Sewage Treatment Works at Finham downstream of the City, and over 26 combined sewer overflows being identified and removed (or identified for removal) in 1963 by Coventry City Council, as identified in Section 3.4, the integrity of the sewerage system has improved, but the problem of pollution from persistent illegal and intermittent discharges, particularly during storm events, as identified in Table 3.5, remains.

Routine spot sampling frequencies have been progressively reduced by the National Rivers Authority and subsequently the Environment Agency since 1991 as part of efficiency measures, and the practice of sampling all surface water sewer outfalls of over 300mm diameter, to identify specific drainage systems with pollution problems, in the City ended in the early 1990s due to reprioritisation of resources. The annual water quality reports produced by the Environment Agency (1997 -2002) detail the results of the General Quality Assessment (GQA) (see Section 2.4.2), for sites sampled in progressively fewer and longer stretches of watercourse, as discussed in Chapter 2. Initially many of the monitored sites gave poor results due to unknown contamination sources at the commencement of this study (Environment Agency 1997). Waste Management issues stretched the resources of the newly formed multifunctional Environment Agency Pollution Control teams and proactive pollution prevention visits

and reactive incident response became the principal methods of tackling the problem of failing watercourses in the City.

At the beginning of this investigation, multi-probe water quality monitors were considered costly by the regulatory bodies, and impractical for general day-to-day use, and were only employed by consultants and specialists as part of expensive projects with pre-defined budgets, such as Urban Pollution Monitoring studies. The Water Companies were also wary of taking on the available portable technology, and it was reported that DO probes were prone to fouling. Although improved instruments were available, they were expensive and had a high cost of ownership, requiring a degree of expert attention that was too high for the water industry (Scott 1998). Their application in the Environment Agency was therefore restricted to monitoring sewage effluent impacts in open watercourses such as the River Avon. Spot samples, routine (GQA) analysis and the use of physical obstructions, such as barbed wire strands placed strategically into the surface water sewers, were the tools commonly used to identify and remove intermittent pollutions.

This investigation considered the deployment of continuous water quality monitors to proactively find, and remove, the sources of organic pollution in urban sewerage systems contributing to pollution problems downstream of the City in the River Avon. The report seeks to identify the problems encountered in carrying out such a detailed practical investigation of contamination associated with urban runoff, and discusses the potential for a wider adoption of this approach. Many of the pollution problem areas identified in the project will have been addressed by necessity, or removed by enforcement, and most of the predictions concerning an improvement in water quality or a return to base contaminant concentrations will have been proven at an early stage. The deployment of multiple mobile continuous monitors offers a novel application of UPM

methodology into surface water systems that is not currently routinely employed by the Environment Agency with its limited resources, and may be particularly useful in areas where routine spot sampling for quality purposes is being steadily decreased, unless warranted by discharge consents or specific European legislation. The practical nature of the research highlights the benefits of using continuous monitors to identify actual quality variation and trends, against the use of theoretical models, based on time-series rainfall and hypothetical sources of contaminants presented in convenient `blocks` and `packages`. The use of models may allow improvement of known point source discharges, but will not identify the impact of illegal industrial trade effluents, misconnections and the presence of unknown cross sewer connections and sewer overflows. This Chapter also identifies the limitations and practical difficulties of using continuous monitoring in urban drainage systems (Section 4.7.1).

4.2 Methodology.

To continuously monitor every storm event at all of the points used by the Environment Agency for routine GQA spot sample monitoring (Section 4.1) would be resource intensive, impractical and of little benefit to this study. Three phases of investigation were carried out therefore, to identify the open watercourses, drainage systems and culverted streams which would benefit most from intensive research. The programme of investigation was divided into 3 phases to test the hypotheses (section 1.4), and meet the objectives (Section 1.5) as follows:

Phase 1: The initial determination of culverted watercourses within the River Sowe catchment identified as problematic or potentially containing foul sewerage and illegal trade effluent misconnections using historical water quality data and short periods of continuous monitoring on open watercourses, as detailed in Section 4.2.1. This phase will satisfy objectives 1 and 2, as detailed in section 1.5.

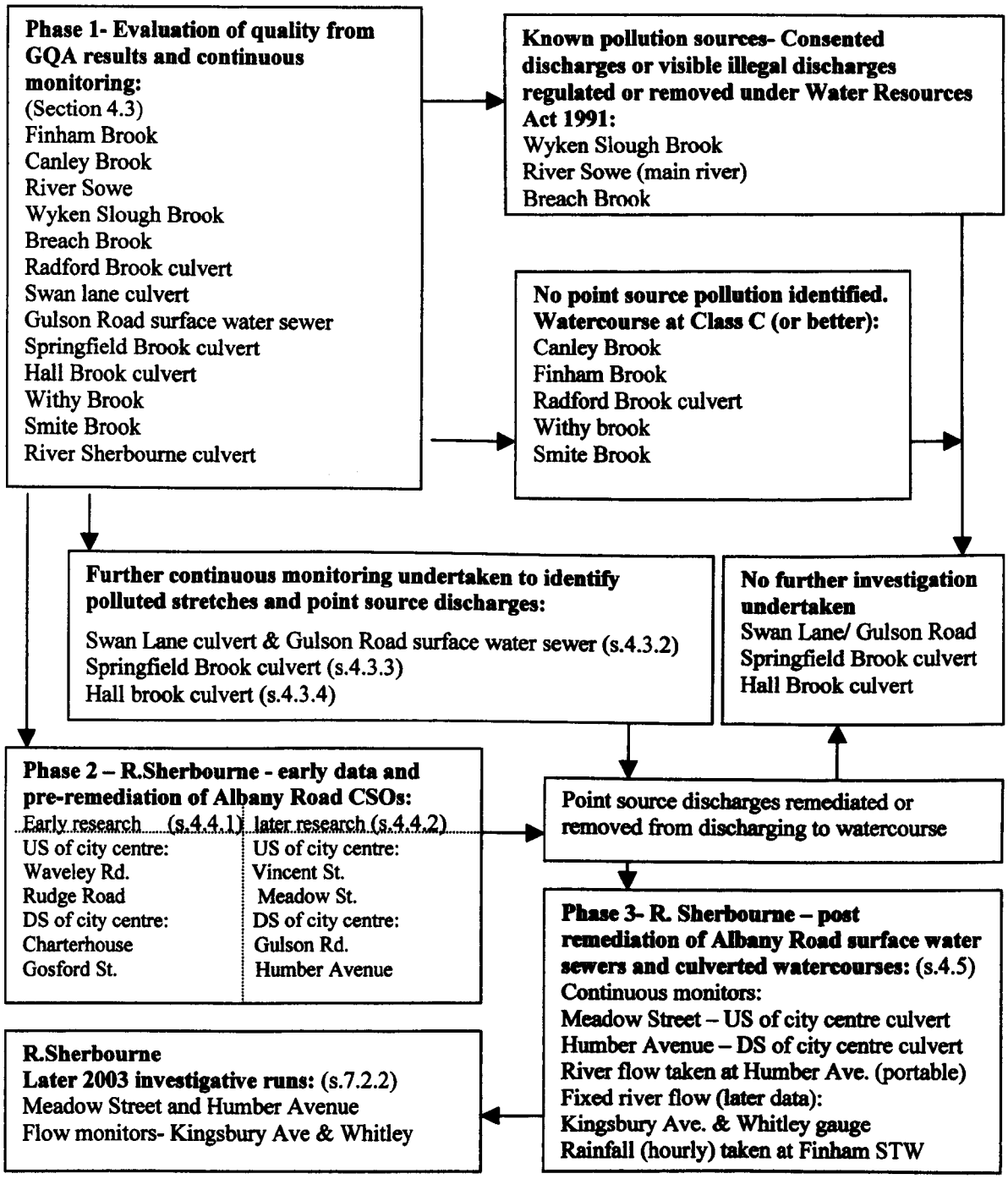
Phase 2; The initial assessment using continuous water quality monitors, of wet weather and dry weather quality in the culverted and open sections of the River Sherbourne associated with poor GQA results downstream of six combined sewer overflows (Section 4.2.2) at Albany Road, which were suspected by the Environment Agency of unsatisfactory operation. This phase also satisfies objective 1 and 2, and provides the baseline data for consideration of any improvement in water quality as identified in objective 3 (Section 1.5).

Phase 3: This is the 'post-remediation' phase, involving the use of continuous monitors and automatic sampling units during dryweather and storm events following major

alterations by Severn Trent Ltd to the Albany Road combined sewer overflow system. It identifies whether organic contaminants remain, whether the contribution of the City surface water system to seasonal problems in the River Sowe and River Avon catchments is significantly reduced, and whether any other contaminants remain that may threaten achievement of water quality standards as they arise through European and domestic legislation, including the Water Framework Directive (200/60/EC) (Section 2.6). The data obtained will be examined to satisfy objective 3, 4 and 5 as detailed in Section 1.5.

To assist in the justification of maintenance costs, the water quality monitors were also used in traditional fashion on open watercourses, to assess the impact of consented point source discharges, providing information in support of Water Company Asset Management Plans (AMP) submissions, and for consent issues and modifications. The monitors were used to trace pollution incidents and to monitor the downstream impact of pollution incidents on the water environment. A watercourse described under the General Quality Assessment (GQA) system (see Section 2.4.2) as 'fairly good' or class C, would be required to have a Biochemical Oxygen Demand of 6 mg l^{-1} or less as a 90 percentile, an ammonium concentration of 1.3 mg^{-1}, and a DO saturation of 60% or more. These guidelines were compared to continuous monitor results, to determine whether there were continuous or intermittent polluting discharges upstream of the monitoring point (see Section 4.3). The three phases of research into urban pollution sources are summarised as a flow chart (Figure 4.1).

Figure 4.1 Identification of pollution sources in the River Sowe catchment



4.2.1 Continuous water quality monitors used during phase 1, 2 and 3

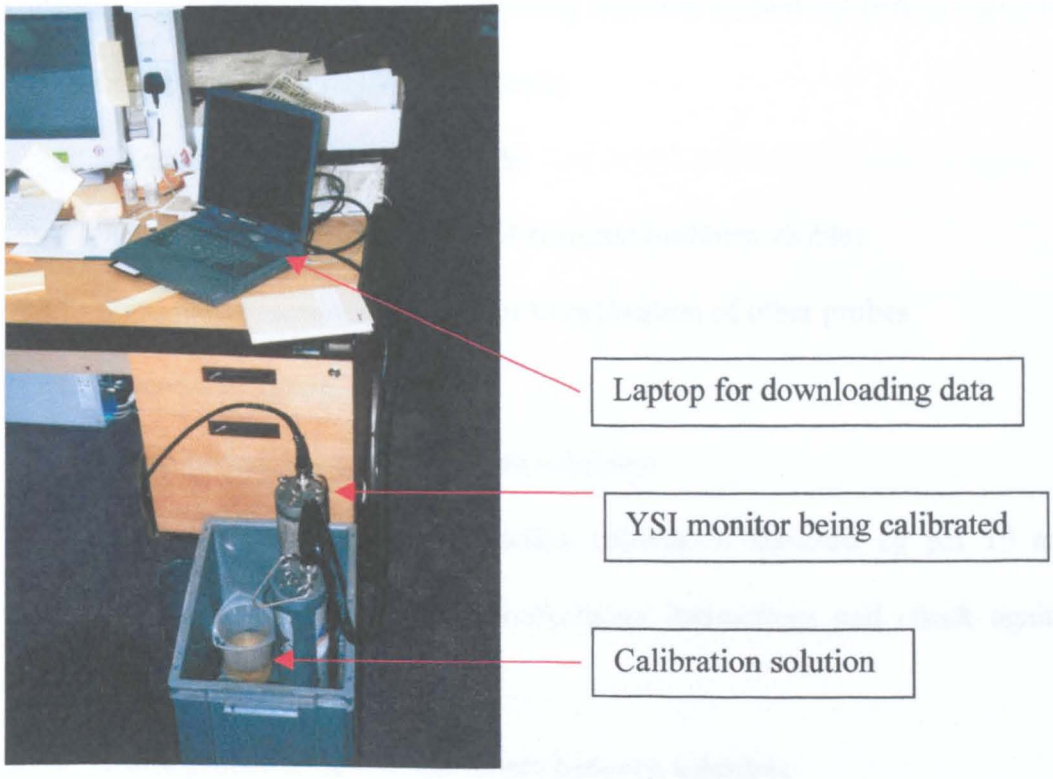
To implement the use of continuous monitors to determine water quality variations in the River Sowe catchment at times of, and during, storm events, key locations were

identified in the Rivers Sowe and Sherbourne according to accessibility and expected impact from urban systems. Initially three Grant/YSI 3800 monitors were used for water quality monitoring in open watercourses across the City. These units each had a separate logger unit connected to a sonde. The monitors were installed in open sections of watercourse chained to fixed objects such as trees, pipes and railings. The logger had to be kept dry whilst the sonde had to be kept permanently submerged in the flow. When, in 1997 YSI 6000 units (see Figure 4.2) began to replace the 3800 models, they offered the benefit of having a logger unit incorporated within the sealed sonde and were therefore much easier to install in the field. The smaller YSI 600 XLM models (left of Figure 4.2), and more recently the YSI 6920, as shown to the right of Figure 4.2, have been used in relatively small-bore drainage systems. All were used to monitor and record pH, DO, conductivity and ammonia. Models were interchangeable according to their calibration and repair status. The equipment used is shown in Figures 4.2 and 4.3.

Figure 4. 2: YSI water quality monitors

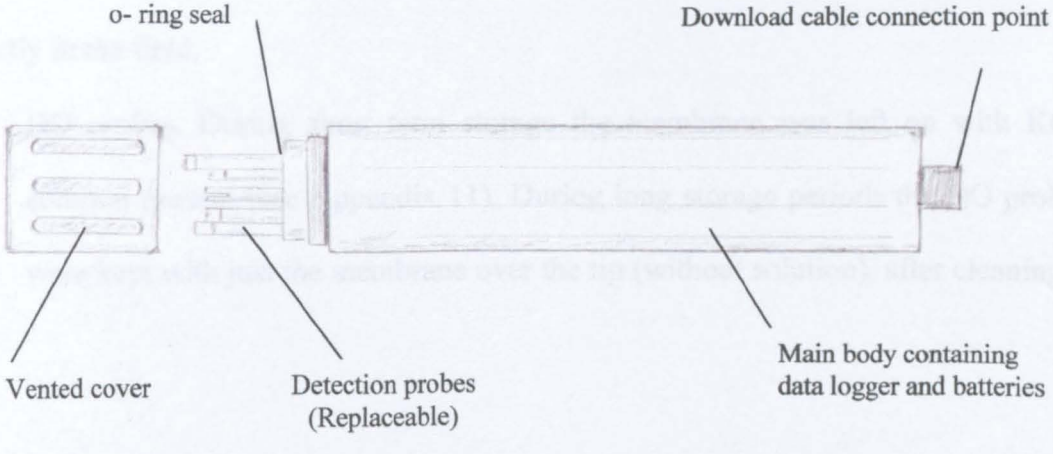
Key to Figure 4.2:
a - YSI 600XLM
b - YSI 6000 series
c - YSI 6920

Figure 4.3: Calibration of YSI monitors



The YSI monitors have replaceable probes as shown in Figure 4.4, allowing for the determination of DO (percentage saturation and concentration), conductivity, temperature, pH, ammonium nitrogen, unionised ammonia, turbidity and chloride, according to which combination of probes are utilised.

Figure 4.4 Diagrammatic representation of a YSI multiprobe continuous water quality monitor



4.2.2 Calibration of YSI continuous monitoring equipment

Cleaning and calibration of each monitoring unit was carried out before each monitoring run to ensure consistent results, as follows;

1. Clean monitor and probe guards
2. Replace DO probe membrane if required (bubbles visible)
3. Remove ammonium probe prior to calibration of other probes
4. Connect to laptop
5. Rinse probes in fresh calibration solutions
6. Calibrate probe against respective calibration standard eg pH 10 and pH 7 solutions as identified in manufacturers instructions and check against given calibration ranges
7. Rinse probes in de-ionised waters between solutions
8. Replace ammonium probe and check against calibration range using standard solutions at 4°C and room temperature
9. Set programme and location and install on site immediately

A detailed procedure for pre-calibration assembly, and calibration of each probe is given in Appendix 11.

i) Probe storage.

Storing the probes properly is very important in order for them to last and to function correctly in the field.

- DO probes. During short term storage the membrane was left on with KCL solution present (see Appendix 11). During long storage periods the DO probes were kept with just the membrane over the tip (without solution), after cleaning.

- The pH probe was cleaned and then immersed within a pH 7 solution for a few days after use. During a prolonged period without use, the tips were kept moist within this solution.
- Ammonium tips were always be kept within a 100mg l^{-1} solution when not in the field or being calibrated.

ii) Quality assurance

Verification of calibration methods by Hydrodata Ltd was carried out annually, and all probes were cross calibrated and maintained on a quarterly basis by the Environment Agency's data monitoring team based at Trentside, Office, Nottingham. The monitors were inspected for damage following use, and all probes were cleaned and inspected before and after each monitoring run, with replacement probes installed as required.

The parameters measured by each of the continuous monitors are given in Table 4.1:

Table 4.1 Typical performance specifications for YSI continuous monitors (YSI)

parameter	Range	Resolution	Accuracy	Method
DO % saturation	0-500%	0.1%	0-200% ±2% 0-500% ±6%	Rapid pulse (Clark type) polarographic
DO concentration (mg l^{-1})	0- 50	0.001	0-200 ±2 mg l^{-1} 0-500 ±6 mg l^{-1}	Calculated from % sat., temp and salinity
Conductivity (mS cm^{-1})	0-100	0.001- 0.1	±0.5% + 0.1 mS cm^{-1}	Thermistor probe
Temperatue (°C)	-5 to +45	0.01	±0.15°C	Thermistor probe
pH (pH units)	0-14	0.01	± 0.2 units	Glass combination electrode
Ammonium (N) (Total) (mg l^{-1})	0-200	0.001- 1.0	±10% Or 2 mg l^{-1} whichever is greatest	Ion sensitive membrane
Ammonia unionised (mg l^{-1})	0-200	0.001- 1.0	±10% Or 2 mg l^{-1} whichever is greatest	Ion sensitive membrane
Turbidity (NTU)	0- 1000	0.1	±5% Or 2 NTU whichever is greatest	Ion sensitive membrane
Chloride (mg l^{-1})	0- 1000	0.001 – 1.0	± 15% Or 5 mg l^{-1} whichever is greatest	Ion sensitive membrane

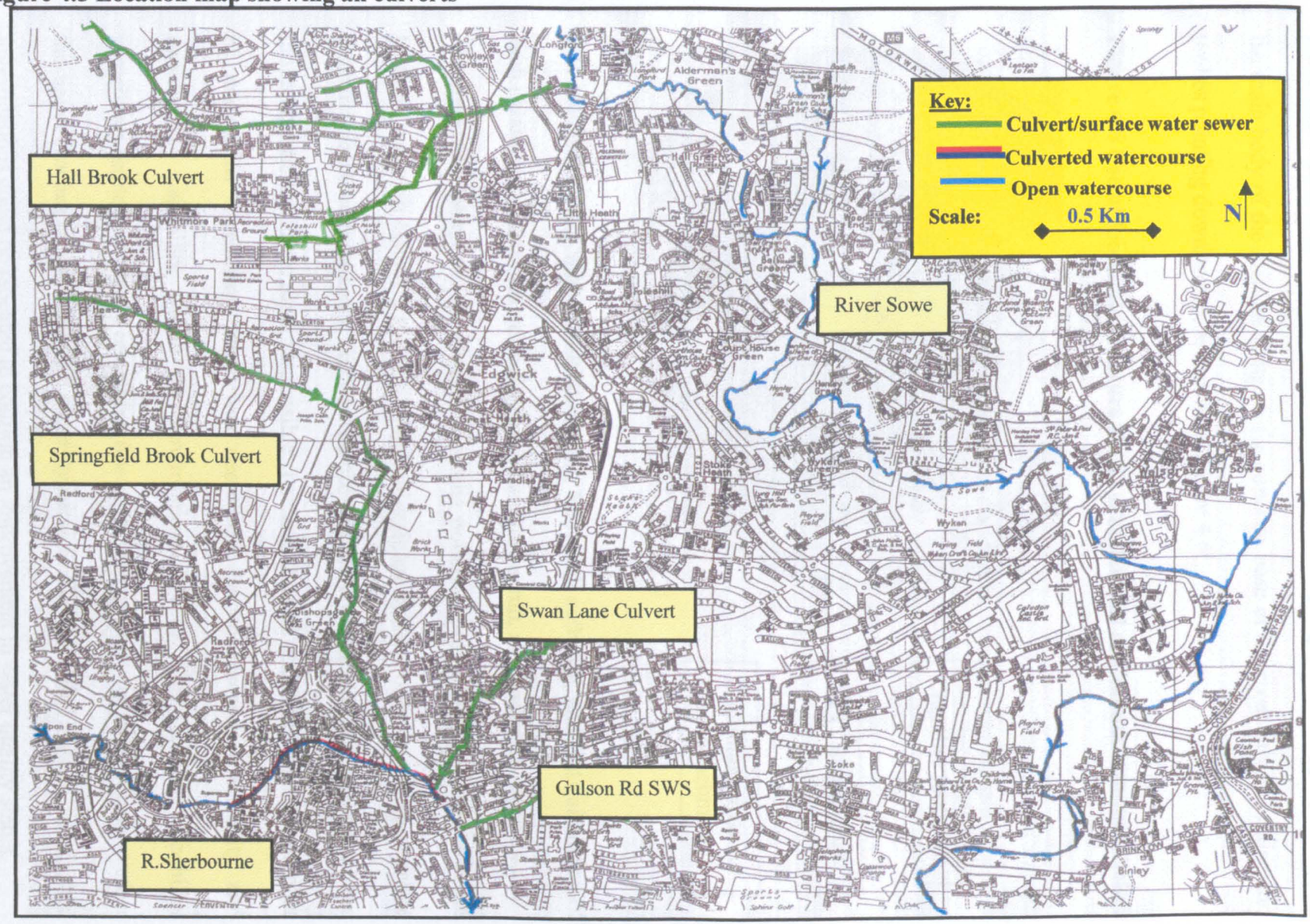
4.3 Phase 1 Identification and investigation of problematic culverted watercourses in the River Sowe catchment

All of the watercourses in the River Sowe catchment were monitored progressively for a period of two weeks each, to identify if high concentrations of total ammonium and low saturation percentages of dissolved oxygen, relative to indicative levels for a class C watercourse (Section 4.2), indicated the presence of illegal or intermittent polluting discharges. The River Sowe, Finham Brook, Canley Brook, Wyken Slough Brook, Breach Brook and the culverted Radford Brook (see Figure 3.1 and Figure 3.2) were all selected for monitoring using continuous monitors during 1997 and 1998, and discounted from the investigation, as having relatively stable water quality variations which did not indicate the presence of intermittent or unknown polluting discharges, or as having pollution from controlled sites, with known discharge points. Where problems were recorded from individual sites, (such as the hospital site in Walsgrave on the River Sowe), they were easily identified due to the open nature of the watercourse, investigated further, and any misconnected foul sewage discharges and illegal trade effluents removed or redirected to the foul sewer. Long term pollution problems from specific industrial pollution sites (requiring investigation), and at outlets arising from poor pollution prevention measures, chemical storage and contaminated land issues, (such as those occuring in the North of the City), may continue for many years, and fall outside the scope of this report. Dunlop Ltd, on the culverted Hall Brook catchment was considered in this study only as a result of trying to identify other, more domestic problems, (identified by public complaint and visual identification of sewage debris), which required further investigation on the same drainage system (Section 4.3.4).

As problem areas were identified and narrowed down to smaller sections of open watercourse using these continuous monitors, (and within culverts using visual

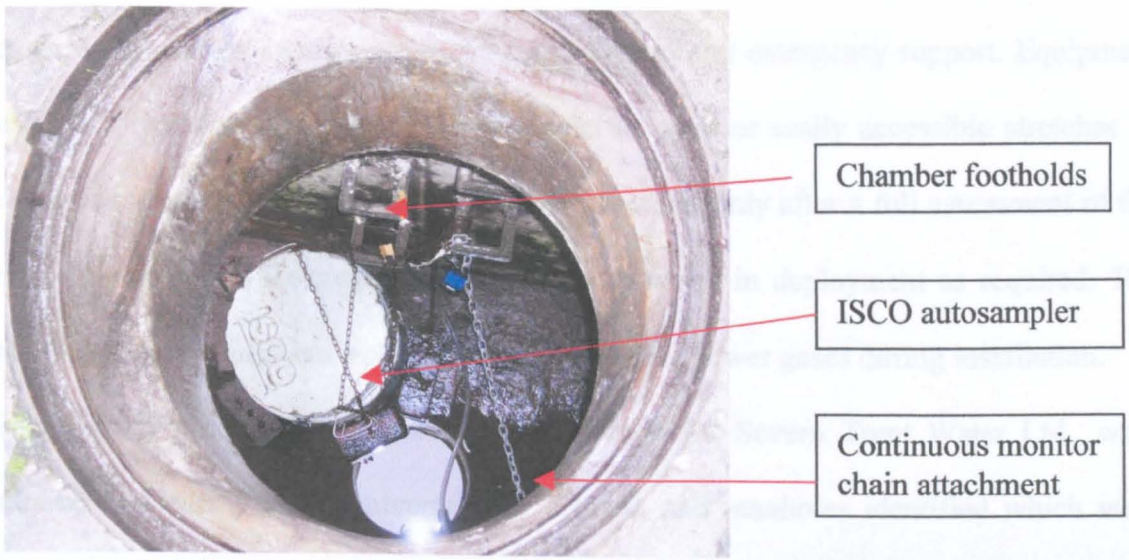
indicators such as floating sewage matter, debris caught on chains and debris caught on strands of barbed wire placed at strategic locations), it became necessary to install monitors into the culverts. The use of continuous monitors allowed for the graphical representation of up to two weeks of data for conductivity, pH, DO, ammonia, turbidity and temperature to identify potential pollution sources. The Swan Lane Culvert, Gulson Road surface water sewer, Springfield Brook Culvert draining to the River Sherbourne, and Hall Brook Culvert draining to the River Sowe, were identified as potentially contaminated by reason of the high concentrations of total ammonium or poor DO content monitored at the outfall of the culverted stream or sewer. They were chosen for further investigation at a number of points along the drainage system, using the continuous monitors. The location of these culverts in relation to the Rivers Sowe, Sherbourne and the city centre is shown in Figure 4.5, and the data obtained from monitoring them at accessible manhole chambers over time, is given in Section 5.1.

Figure 4.5 Location map showing all culverts



The monitors and auto-samplers were installed using chains and padlock attached to pipes and chamber footholds in the vicinity of the sampling point as appropriate, with the main body of the monitor lying on the concrete base of the river culvert or pipe and probes pointing downstream, as shown in Figure 4.6:

Figure 4.6 Use of footholds to secure ISCO sampler and continuous monitor chains



The monitoring data was downloaded using Ecowatch software, and full calibration of each parameter was carried out before each monitoring run, as detailed in Section 4.2.2. The data was interpreted to identify potential pollution problems, and justify a more targeted approach against a specific stretch of drainage system, often involving resource intensive invasive techniques, such as the use of CCTV monitoring and fluorescent dye to identify the discharge pipes responsible. Towards the end of this research, the number of maintained monitoring units was decreased due to resource availability and maintenance capability within the Environment Agency. This reduced capability sometimes limited where the remaining few units were placed, and determined whether the upper reaches of some surface water systems could be studied further, or whether investigations could be repeated to confirm an improvement in water quality status.

4.3.1 Health and Safety considerations

The Health and Safety at Work Act, 1974, requires of the Environment Agency, that any employee of the Environment Agency undertaking work on behalf of the Agency or using Agency owned equipment is provided with all the necessary personal protective equipment (PPE) and other safety measures, as is required following a risk assessment of the tasks to be undertaken. No confined spaces, such as culverts or sewers can be entered without the appropriate training, equipment and emergency support. Equipment used in this research was therefore deployed in open or easily accessible stretches of watercourse, or in culverts and surface water systems only after a full assessment of the risks involved, and the availability of others to assist in deployment as required. The manholes were vented beforehand and monitored for sewer gases during installation.

Sewer maps produced by Coventry City Council for Severn Trent Water Ltd., were studied to identify where culverts were located, and manholes identified which were easily opened using available equipment and limited manpower, and which were not situated in the middle of major trunk roads. The manufacturers of the monitoring units and Coventry City Council drainage engineers were consulted on the use of the units in culverted watercourses from a health and safety point of view, and both agreed that the potential risk of explosion from using the equipment on this drainage system was negligible.

Health and Safety was the over-riding factor in deployment of the equipment at all times, and occasionally data was not obtained as a result; for example in times of flooding or high culvert flow velocities or where traffic volume may have prevented access to a culvert monitoring point at a particular time. The latter consideration was particularly relevant to investigations on the Springfield Brook (Section 4.3.3), and Swan Lane (Section 4.3.2) culverts.

4.3.2 Swan Lane Culvert Catchment and Gulson road surface water sewer

The Swan Lane culverted watercourse and Gulson Road surface water sewer were monitored between January 1999 and January 2000, as detailed in Table 4.2, and the results are given in Appendix 1, and discussed in Section 5.2.1. Both systems outfall to the lower reach of the River Sherbourne culvert, within a distance of 200 metres from the outfall to open watercourse. Between January 6 and February 29 1999, the system was investigated using YSI 6000 monitors as shown in Table 4.2. The location of the culvert is shown in Figure 4.7

Table 4.2 **Continuous monitoring in Swan Lane Culvert and Gulson Road surface water sewerage system.**

Date	Location
6/1/99 to 11/1/99	Top of Gulson Road (manhole 799)
13/1/99 to 24/1/99 Gulson Road SWS	Clara Street Top of Gulson Road (manhole 799) Gulson Road
13/1/99 to 24/1/99 Swan Lane culvert	Berry Street Hood Street
29/1/99 to 9/2/99 Swan Lane culvert	King Edward Road Berry Street Swan Lane manhole 796
17/2/99 to 26/2/99 Swan Lane culvert	Swan Lane manhole 796

4.3.3 Springfield Brook Catchment

In December 1997 the sources of water quality problems on the Springfield Brook catchment were investigated using continuous monitors. Elevated ammonium and low DO concentrations had previously been recorded in spot samples taken from the open stretch of watercourse at Matlock Road, and subsequently a manhole near to the confluence with the River Sherbourne. The location of the culvert is shown in Figure 4.8. Seven monitoring runs were undertaken on the Springfield Brook between December 1997 and April 2001, as shown in Table 4.3. The results are given in Appendix 2, and discussed in Section 5.2.2.

Table 4.3 **Continuous monitoring in the Springfield Brook Culvert**

Date	Location	
12/12/97 to 2/1/98	Bowness Close Joseph Cash School Courtaulds site Cash's Lane Planet Carpark	
2/3/98 to 9/3/98	Courtaulds site Cash's Lane Springfield Place	
24/3/98 to 2/4/98	Courtaulds site Springfield Place Planet Carpark	
29/7/98 to 2/8/98	Courtaulds site Cash's Lane	
14/8/98 to 24/8/98	Courtaulds site Cash's Lane Springfield Place Planet Carpark	
23/03/01 to 10/4/01	Dicken's Road Borrowdale Close Guardhouse Road Owenford Road	Kingfield Road Cash's Lane Planet car park

4.3.4 Hall Brook Catchment

The Hall Brook catchment was the only culverted watercourse investigated which drains directly into the River Sowe. Eleven monitoring runs were undertaken on the two main arms of the Hall Brook between September 1998 and July 2000, as shown in Table 4.4. The results are given in Appendix 3, and discussed in Section 5.2.3. The locations of the monitoring points on this culverted watercourse are given in Figure 4.9.

Table **4.4 Continuous monitors placed in Hall Brook culvert**

Date	Location
2/9/98 to 12/9/98	St Paul's cemetery Kirkdale Avenue manhole 913 (Hen Lane arm) Foleshill gasworks
23/9/98 to 3/10/98	Doyle Drive at outfall to R.Sowe Hen Lane manhole 052 Marshdale Avenue – Dunlop arm manhole 113 Marshdale Avenue – Colliery arm manhole 115
16/10/98 to 26/10/98	Lythalls Lane manhole 971 Marlisa Drive Hen Lane manhole 052 Marshdale Avenue, Dunlop arm manhole 113 Marshdale Avenue– manhole 115
5/8/99 to 15/8/99	Hen Lane manhole 052 Marshdale Avenue – Parkgate school arm manhole 114 Marshdale Avenue – Dunlop arm manhole 113 Hall brook at Marlisa SWS discharge Lythalls Lane manhole 971
6/12/99 to 12/12/99	Hen Lane manhole 052 Marshdale Avenue – Parkgate arm manhole 114 Marshdale Avenue – Dunlop arm manhole 113 Lythalls Lane manhole 971 St Paul's cemetery
14/1/00 to 24/1/00	Lythalls Lane manhole 973 Allied Close manhole 082 Stadium Close gattic type (large concrete) cover Dunster Place gattic type (large concrete) cover
11/2/00 to 21/2/00	Lythalls Lane –manhole 974 Lythalls Lane – manhole 971 Allied Close manhole 082 Stadium Close Dunster Place
10/3/00 to 20/3/00	St Paul's cemetery Holbrook Lane manhole 534 Holbrook Lane manhole 544
12/05/00 to 22/5/00	St Paul's cemetery Holbrook Lane manhole 544 Holbrook Lane manhole 533 Holbrook Lane manhole 534 Foleshill park upstream of Dunlop interceptor Foleshill park downstream of Dunlop interceptor
2/6/00 to 19/6/00	Foleshill park upstream of Dunlop interceptor Foleshill park downstream of Dunlop interceptor
29/6/00 to 9/7/00	Dunlop site drainage (monitoring point 21, figure 4.9) Holbrook Lane downstream of Dunlop at manhole 534

The location of the Hall Brook Culvert and monitoring points is shown in Figure 4.9.

Figure 4.7 Location plan of Gulson Road SWS and Swan lane Culvert

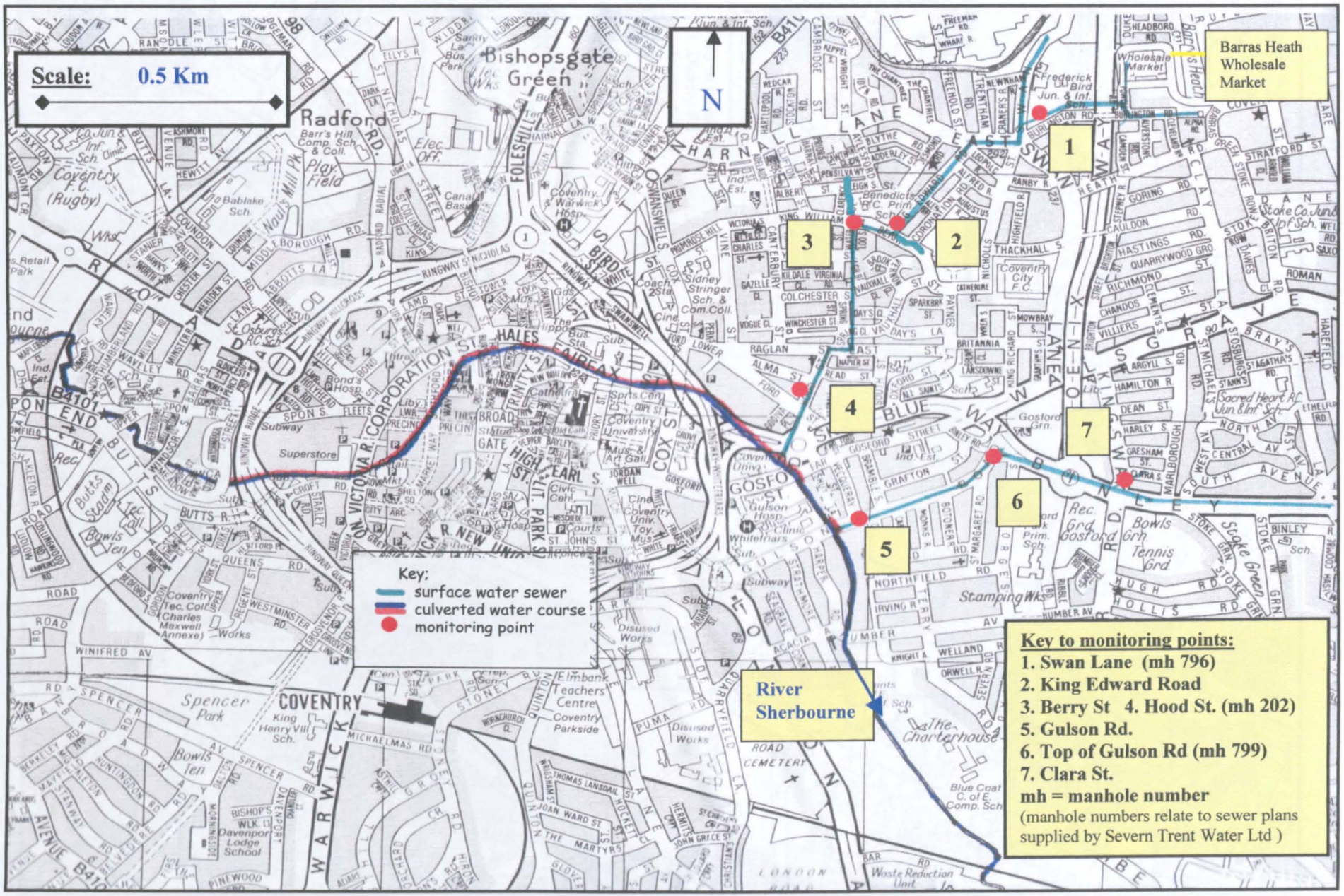


Figure 4.8 Location of Springfield Brook Culvert

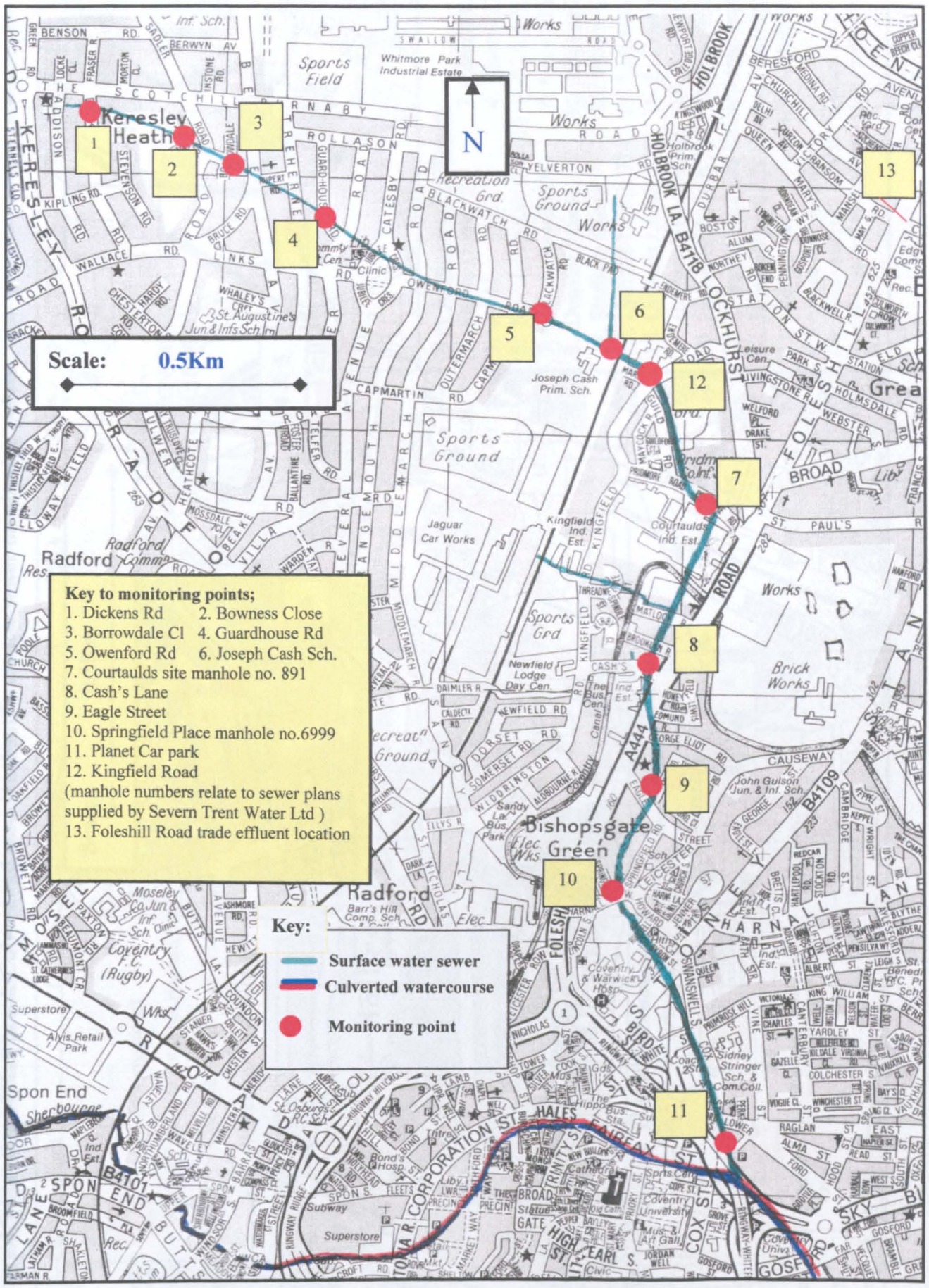
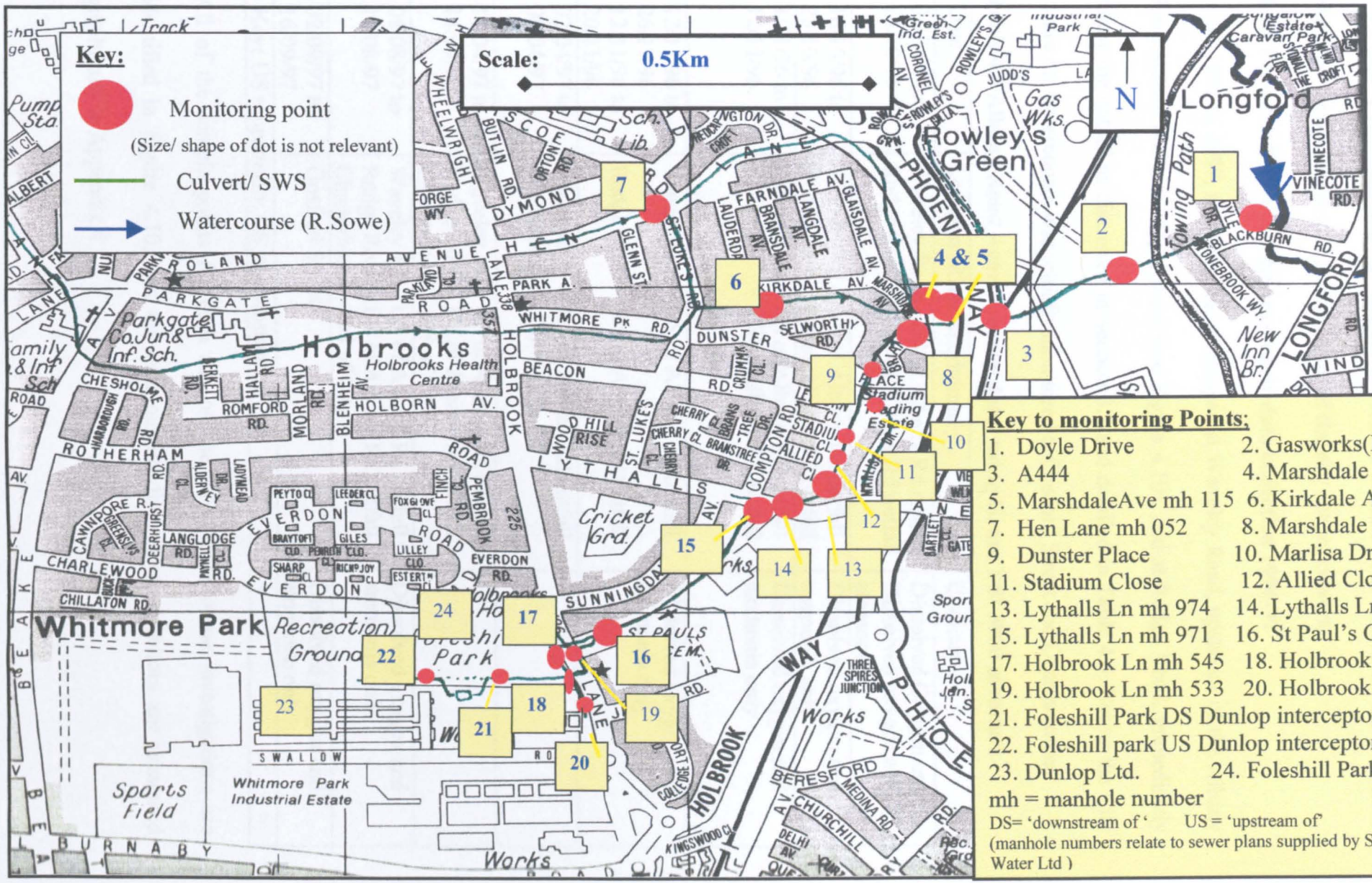


Figure 4.9 Location of Hall brook Culvert and associated surface water sewer monitoring points



4.4 Phase 2 Investigating the impact of Albany Road storm overflows on the River Sherbourne upstream and downstream of the city centre culvert.

4.4.1 Pre-remediation conditions – early data collection 1996-97

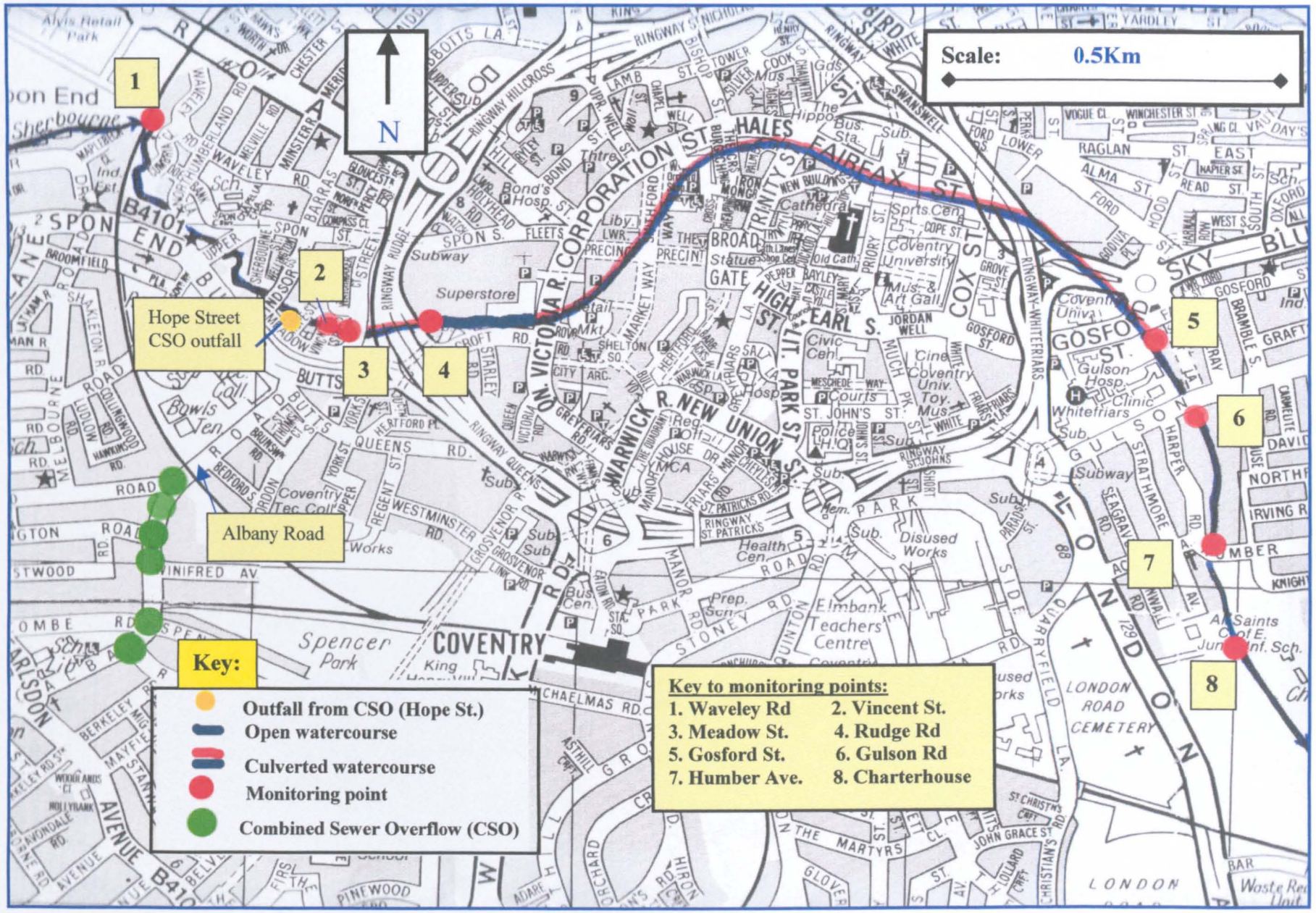
From 1996 to 1997, monitors were deployed at Waveley Road, upstream of the Albany Road system outlet at Hope Street (see Figure 4.10), and at Rudge Road, immediately below the outfall as discussed in Section 3.2 and detailed in Table 4.5. Below the City centre the watercourse was initially monitored at Gosford Street and Charterhouse.

Table 4.5 Albany Road – early survey dates using Grant YSI 3800 monitors

Date	Location (River Sherbourne)	Comments
3/10/96 to 14/10/96	Waveley Road– US of Albany Rd outfall Rudge Road – DS of Albany Rd outfall	Dissolved Oxygen only. Dissolved oxygen and ammonia
16/10/96 to 28/10/96	Waveley Rd – US of Albany Rd outfall Rudge Rd – DS of Albany Rd outfall	Dissolved oxygen and ammonia only
1/11/96 to 12/11/96	Waveley Rd – US of Albany Rd outfall Rudge Rd – DS of Albany Rd outfall	Dissolved oxygen and ammonia only
12/11/96 to 26/11/96 12/11/96 to 20/11/96	Waveley Rd – US of Albany Rd outfall Rudge Rd – DS of Albany Rd outfall	Dissolved oxygen and ammonia only
02/04/97 to 08/04/97	Rudge Rd – DS of Albany Rd outfall Charterhouse – DS of City	
11/04/97 to 14/04/97	Waveley Rd – US of Albany Rd outfall Rudge Road – DS of Albany Rd outfall Charterhouse – DS of City	
08/08/97 to 19/08/97	Waveley Rd – US of Albany Rd outfall Rudge Road – DS of Albany Rd outfall Charterhouse – DS of City	Dissolved oxygen and ammonia only
02/09/97 to 16/09/97	Gosford Street	Dissolved oxygen and ammonia only
Key: US = upstream; DS = downstream		

All of the sample points for each run on the River Sherbourne investigations are identified in Figure 4.10, and the data outputs from these monitors are presented graphically in Appendix 4.

Figure 4.10 Location of River Sherbourne monitoring points and Albany Road combined sewer overflows (CSOs)



The Waveley Road monitoring point is in an urban catchment, and is downstream of a consented pumping station storm overflow in the lower reaches of the Pickford Brook (Figure 3.2), but is upstream of the Albany Road CSOs and the City centre. The data collected at the monitoring points upstream and downstream of the Hope Street outfall was presented to Severn Trent Water Limited and the Regional Water Quality department of the Environment Agency, and a submission under the Asset Management Programme (NRA, 1993) was eventually agreed as detailed in Section 3.2. In response to the findings, one sewer overflow on Albany road was identified for immediate removal and the conversion of an adjacent surface water sewer to provide greater storage capacity as a second foul sewer with only one high level storm overflow, was agreed, as shown in Figure 3.4. Monitoring runs carried out from October 1999 to completion of the work in October 2000, and thereafter in the post-remediation phase, were concentrated at Meadow Street above the culverted section of the watercourse, and, downstream of the City centre at Gulson Road, and later Humber Avenue, as shown in Figure 4.10.

4.4.2 Pre-remediation Investigations 1999- 2000

Pre remediation investigations carried out as part of this project between October 1999 and September 2000 are identified in Table 4.6. All monitoring runs were carried out on the River Sherbourne at Vincent Street and Meadow Street upstream of the city centre, and at Gulson Road or Humber Avenue, which are both downstream of the culverted stretch, unless stated otherwise. The locations of monitoring points for Phase 2 and Phase 3, are given in Figure 4.10.The monitoring site at Rudge Road (used for early data collection) was abandoned as a viable site, following vandalism of the monitoring equipment. Some runs involved automatic sampling using an ISCO automatic sampler as shown in Figure 4.4. The results of these investigations are given in Appendix 5, and discussed in Section 6.1.

Table 4.6 Phase 2: Data Collection dates from October 1999 to September 2000

Run No.	Start Date	End Date	Data/ Sample Type	Location	Duration	Reference on graph	Comments
1	1-Oct-99	1-Oct-99	Continuous	Vincent Street	12 Hours		
	1-Oct-99	1-Oct-99	Continuous	Gulson Road	12 Hours		
	14-Oct-99	14-Oct-99	Continuous	Vincent Street	12 Hours		
	14-Oct-99	14-Oct-99	Continuous	Gulson Road	12 Hours		
2	2-Mar-00	3-Mar-00	Auto - spot sample	Humber Avenue	24 hours	Auto 1	
3	10-Mar-00	10-Mar-00	Auto - spot sample	Humber Avenue	24 hours	Auto 2	Only 2 results
4	15-Mar-00	16-Mar-00	Continuous	Humber Avenue	24 hours	Humber storm	
	15-Mar-00	16-Mar-00	Continuous	Meadow Street	24 hours	2 Meadow	
	15-Mar-00	15-Mar-00	Auto - spot sample	Humber Avenue	24 hours	Auto 3	
5	23-Mar-00	24-Mar-00	Auto - spot sample	Humber Avenue	24 hours	Auto 4	
6	29-Jun-00	9-Jul-00	Continuous	Humber Avenue	24 hours		
	29-Jun-00	9-Jul-00	Continuous	Meadow Street	24 hours		
7	28-Sep-00	29-Sep-00	Continuous	Humber Avenue	24 hours	Humber 1	
	28-Sep-00	29-Sep-00	Continuous	Meadow Street	24 hours	Meadow 1	
	28-Sep-00	29-Sep-00	Flow	Humber Avenue	24 hours		
	28-Sep-00	29-Sep-00	Auto - spot sample	Humber Avenue	24 hours	Auto 5	

4.5 Phase 3 Investigation of post-remedial conditions in the River Sherbourne upstream and downstream of the city centre culvert

Following implementation of the scheme to replace the Albany Road combined sewer overflows, the variability of water quality was assessed on the river Sherbourne in the centre of Coventry. Continuous monitors were installed at locations away from public access at Meadow Street above and Humber Avenue below the culverted stretch of the River Sherbourne and data obtained for dry weather and storm events as shown in Table 4.7.

Table 4.7 Investigation Numbers - Data Collection dates October 2000 – November 2003 (post-remediation surveys) Sheet 1

Investigation No.	Start Date	End Date	Data/ Sample Type	Location	Duration	Graph reference	Comments
8	16-Oct-00	23-Oct-00	Continuous	Humber Avenue	7 days	Humber 2	
	16-Oct-00	23-Oct-00	Continuous	Meadow Street	7 days	Meadow 2	
	16-Oct-00	18-Oct-00	Flow	Humber Avenue	24 hours		
9	30-Oct-00	13-Nov-00	Continuous	Humber Avenue	14 days	Humber 3	
	30-Oct-00	13-Nov-00	Continuous	Meadow Street	14 days	No Data recorded	**Monitor Stolen so no data available**
	30-Oct-00	5-Nov-00	Weekly stats rainfall	Finham STW	6 days	WS1 Humber 3	**See table key for location of Finham STW**
	30-Oct-00	13-Nov-00	Flow	Humber Avenue	14 days		
10	23-Nov-00	7-Dec-00	Continuous	Humber Avenue	14 days	Humber 4	
	23-Nov-00	7-Dec-00	Continuous	Meadow Street	14 days	Meadow 4	Replacement monitor placed inside culvert for increased security following theft in November
	23-Nov-00	26-Nov-00	Weekly stats rainfall	Finham STW	4 days	WS2 Humber 4	
	6-Dec-00	7-Dec-00	Auto - spot sample	Humber Avenue	2 days	Auto 6	
	6-Dec-00	7-Dec-00	Flow	Humber Avenue	2 days		
11	19-Dec-00	21-Dec-00	Continuous	Humber Avenue	2 days	Humber 5	
	19-Dec-00	13-Jan-01	Continuous	Meadow Street	19 days	Meadow 5	
	19-Dec-00	20-Dec-00	Auto - spot sample	Humber Avenue	2 days	Auto 7	
	19-Dec-00	22-Dec-00	Weekly stats rainfall	Finham STW	3 days	WS3 Humber 5	
12	30-Jan-00	23-Feb-00	Continuous	Humber Avenue	25 days	C1	
	30-Jan-00	23-Feb-00	Continuous	Meadow Street	25 days	C1	
	30-Jan-00	23-Feb-00	Flow	Humber Avenue	25 days		Depth only
	19-Jan-01	21-Jan-01	Weekly stats rainfall	Finham STW	3 days	WS4 Humber C1	
13	23-Feb-01	14-Mar-01	Continuous	Humber Avenue	21 days	C2	
	23-Feb-01	14-Mar-01	Continuous	Meadow Street	21 days	C2	
	9-Mar-01	10-Mar-01	Auto - spot sample	Humber Avenue	2 days	Auto 8	
	12-Mar-01	13-Mar-01	Auto - spot sample	Humber Avenue	2 days	Auto 9	
	1-Mar-01	4-Mar-01	Weekly stats rainfall	Finham STW	5 days	WS5 Humber C2	
14	14-Mar-01	6-Apr-01	Continuous	Humber Avenue	23 days	C3	
	14-Mar-01	6-Apr-01	Continuous	Meadow Street	23 days	C3	
	15-Mar-01	17-Mar-01	Auto - spot sample	Humber Avenue	3 days	Auto 10	Featured in text
	2-Apr-01	3-Apr-01	Auto - spot sample	Humber Avenue	2 days	Auto 11	
	14-Mar-01	18-Mar-01	Weekly stats rainfall	Finham STW	5 days	WS6 Humber C3	

Table 4.7 Investigation Numbers - Data Collection dates October 2000 – November 2003 (post-remediation surveys) Sheet 2

Investigation No	Start Date	End Date	Data/ Sample Type	Location	Duration	Graph reference	Comments
15	6-Apr-01	30-Apr-01	Continuous	Humber Avenue	21 days	C4	
	6-Apr-01	30-Apr-01	Continuous	Meadow Street	21 days	C4	
	9-Apr-01	30-Apr-01	Flow	Humber Avenue	21 days	Flow C4	Flow 9-30th
16	30-Apr-01	15-May-01	Continuous	Humber Avenue	24 days	C5	
	30-Apr-01	15-May-01	Continuous	Meadow Street	24 days	C5	
	07-May-01	15-May-01	Flow	Humber Avenue	21 days	Flow C5	Flow 7th – 15th
17	17-May-01	06-Jun-01	Continuous	Humber Avenue	21 days	C6	
	17-May-01	06-Jun-01	Continuous	Meadow Street	21 days	C6	
	17-May-01	06-Jun-01	Flow	Humber Avenue	21 days	Flow C6	
18	06-Jun-01	29-Jun-01	Continuous	Humber Avenue	23 days	C7	
	06-Jun-01	29-Jun-01	Continuous	Meadow Street	23 days	C7	
	06-Jun-01	16-Jun-01	Flow	Humber Avenue	23 days	Flow C7	Monitor blocked
19	29-Jun-01	27-Jul-01	Continuous	Humber Avenue	29 days	C8	
	29-Jun-01	27-Jul-01	Continuous	Meadow Street	29 days	C8	
	02-Jul-01	27-Jul-01	Flow	Humber Avenue	25 days	Flow C8	
20	27-Jul-01	18-Aug-01	Continuous	Humber Avenue	23 days	C9	
	27-Jul-01	18-Aug-01	Continuous	Meadow Street	23 days	C9	
	27-Jul-01	18-Aug-01	Flow	Humber Avenue	23 days	Flow C9	
21	17-Aug-01	29-Aug-01	Continuous	Humber Avenue	12 days	C10	
	17-Aug-01	29-Aug-01	Continuous	Meadow Street	12 days	C10	
	17-Aug-01	29-Aug-01	Flow	Humber Avenue	12 days	Flow C10	
22	30-Aug-01	16-Oct-01	Continuous	Humber Avenue	18 days	C11	
	30-Aug-01	16-Oct-01	Continuous	Meadow Street	18 days	C11	
	30-Aug-01	16-Oct-01	Flow	Humber Avenue	18 days	Flow C11	

Table 4.7 Investigation Numbers - Data Collection dates October 2000 – November 2003 (post-remediation surveys) Sheet 3

Post –remedial runs 2003						
Investigation No	Start Date	End Date	Data/ Sample Type	Location	Duration	Comments
23	30-Sep-03	----	River Level/ Flow US	Kingsbury Avenue	1 day	Discussed in Chapter 5
	30-Sep-03	----	River Level/ Flow DS	Whitley	1 day	
	30-Sep-03	----	Rainfall	Finham STW	1 day	
	30-Sep-03	----	Auto - spot sample	Humber Avenue	1 day	
	30-Sep-03	----	Auto - spot sample	Meadow Street	1 day	
	30-Sep-03	----	Continuous	Humber Avenue	1 day	
	30-Sep-03	----	Continuous	Meadow Street	1 day	
24	25-Nov-03	26-Nov-03	River Level/ Flow US	Kingsbury Avenue	2 days	Discussed in Chapter 5
	25-Nov-03	26-Nov-03	River Level/ Flow DS	Whitley	2 days	
	25-Nov-03	26-Nov-03	Rainfall	Finham STW	2 days	
	25-Nov-03	26-Nov-03	Auto - spot sample	Humber Avenue	2 days	
	25-Nov-03	26-Nov-03	Auto - spot sample	Meadow Street	2 days	
	25-Nov-03	26-Nov-03	Continuous	Humber Avenue	2 days	
	25-Nov-03	26-Nov-03	Continuous	Meadow Street	2 days	
	KEY:		Auto spot sample		Flow	
			Rainfall (Weekly Stats)		Continuous monitor	
	All rainfall data collected at Coventry (Finham) STW as shown in Figures 3.1 and 3.2 (Hourly) by Severn Trent Water Ltd.					

This research programme monitored the outcome of the AMP scheme and sought to identify what pollutants, if any, were still being discharged to the River Sherbourne by the culverted watercourses previously identified, and the City Centre urban drainage system.

Some continuous monitoring runs were also subjected to hourly spot samples using Automatic samplers. These events are identified in Tables 4.6 & 4.7 as 'Auto' runs. Resource allocation was reviewed at regular intervals, and withdrawn in August 2001. Continuous monitoring without the benefit of automatic spot sampling continued until August 2001, but was then stopped. It was revived again in 2003, and used in combination with automated spot sampling to give information on the current situation in the watercourse.

4.6 Additional equipment used in the practical investigation of water quality status during phase 2 (1999-2000) and phase 3 (post remediation)

4.6.1 Automatic spot sampler

An ISCO 6700 sampler (Figure 4.11 and 4.12) was used to take spot samples of the midstream water for analysis. Samples were taken as hourly composites at 15minute intervals over a period of 24 hours for each run. The samples were collected in 1 litre Propack disposable bags and transferred to the appropriate bottles for analysis at the Environment Agency NAMAS accredited laboratory in Nottingham.

Figure 4.11: **ISCO automatic sampler**

Figure 4.12: **ISCO automatic sampler opened to reveal sample containers**

4.6.2 Flow monitor

The flow monitor used at Humber Avenue was a Rocky Mountain Instruments (RMI) Flowrat 1000, which is a solid-state electronic device with depth and velocity capability, as shown in Figures 4.13 and 4.14:

Figure 4.13 Rocky Mountain Industries (RMI) flow monitor

Figure 4.14: RMI flow monitor securely fastened on site

4.6.3 Rainfall data

Rainfall data was received in tabular form from Severn Trent Water Ltd and relates to precipitation recorded in mm at the Coventry (Finham) sewage treatment works site (Figure 3.1) in Stoneleigh, on an hourly basis.

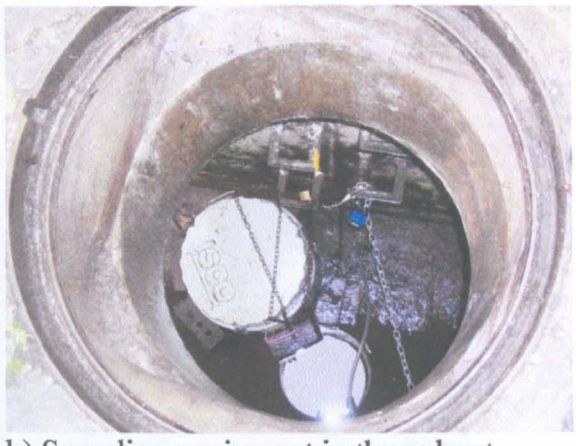
4.7 Location and installation of monitoring equipment

Continuous quality monitors were placed in the River Sherbourne at Meadow Street (upstream of the City Centre), and at Humber Avenue downstream of the City (see Figures 4.15 to 4.19). A Rocky Mountain Industries (RMI) continuous flow-recording device (see Figures 4.13 and 4.14) was deployed at Humber Avenue and stage boards were installed at both sites. Stage board data from Kingsbury Road and Whitley were obtained from the Environment Agency. Spot samples were taken at one-hourly intervals for a 24-hour period during some storm events, and analysed for comparison with continuous data. Samples were analysed for BOD, suspended solids, ortho-phosphate, total phosphate, ammonia, pH, and heavy metals (total zinc, cadmium, copper, chromium, nickel and lead).

Figure 4.15 Location of Albany Road CSO outfall upstream of Meadow Street

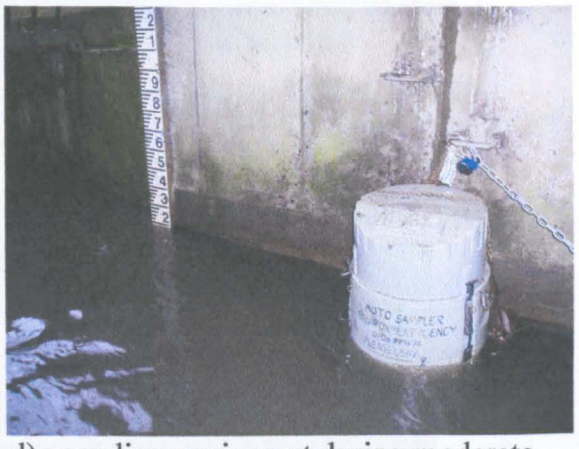
Figure 4.16 (a-d) Monitoring and sampling equipment in situ at Meadow Street

a) Beginning of the culverted section



b) Sampling equipment in the culvert

c) sampling equipment in place during low flows



d) sampling equipment during moderate flows

Figure 4.17(a-b) River Sherbourne culvert upstream and downstream of Meadow Street

a) upstream of monitoring point

b) downstream of monitoring point

Figure 4.18: Monitoring equipment in situ at Humber Avenue

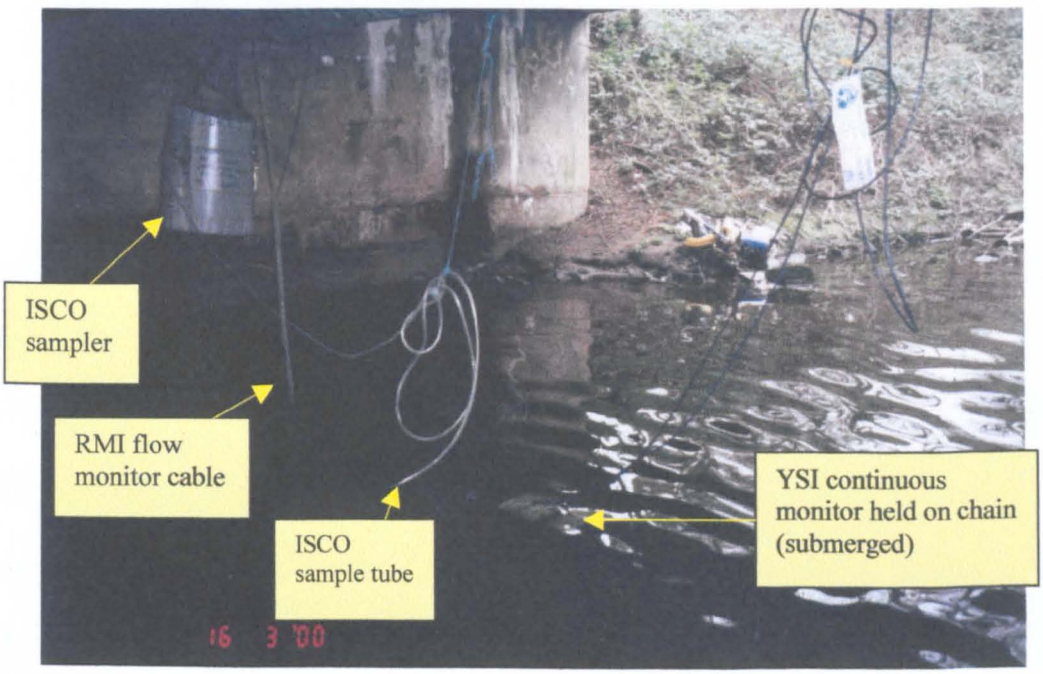
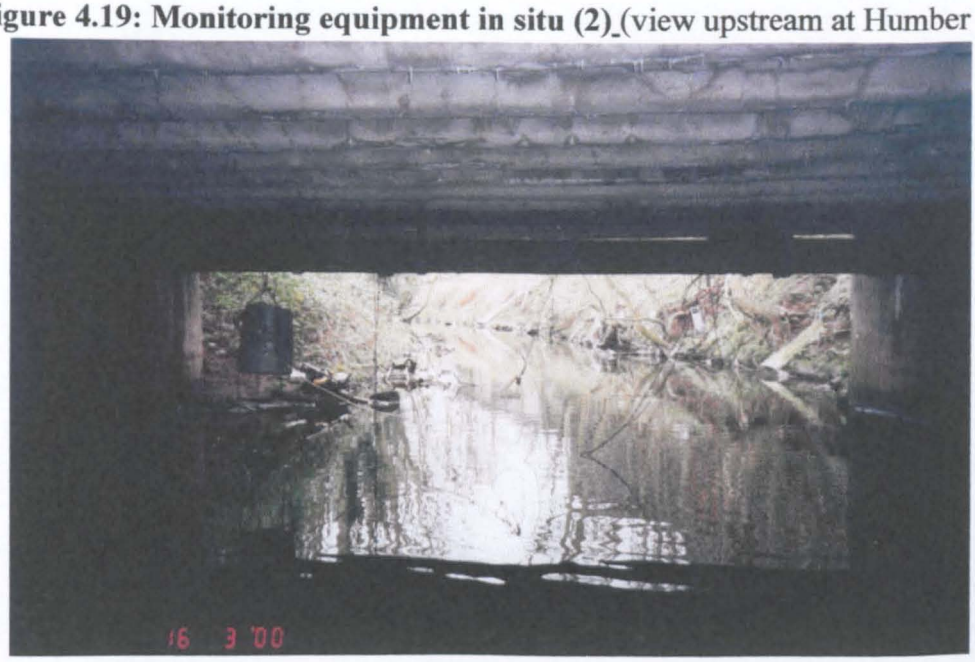


Figure 4.19: Monitoring equipment in situ (2) (view upstream at Humber Ave).



4.7.1 Practical difficulties encountered

In the area of continuous water quality monitoring, the equipment and technology is continually developing and improving. Reliability of probes and the repeatability of data improved substantially in a short period of time, and regular deployment of the equipment led to an increased proficiency in calibration, maintenance and the use of software. In 2000 the official customer support available in the United Kingdom for the

RMI flow-monitoring unit ended, with no UK supplier available to assist in servicing or provision of spare parts for the monitoring units. As a result of this shortfall in customer support, one of the two monitoring units available for use was rendered unserviceable. External factors can be summarised as vandalism, theft, and 'wear-and-tear'. Clearly the monitors are operational equipment, and need to be placed out in the field. It was essential to place the monitors in areas with limited public access. In culverts subjected to high rainfall events the monitors could become damaged after collision with the walls of the culvert, and vandalism of the flow meter and several quality monitors led to valuable data being lost. The theft of one quality monitor also reduced the amount of comparative data available and led to periods of inactivity while a replacement unit was found. Component errors and low flows have also resulted in occasional loss of data or calibration drift (involving one or two probes for short periods in approximately 10% of the monitoring surveys), and major malfunctions such as leaking seals were not discovered until after a two-week monitoring run had been completed, meaning that on two occasions (including the featured storm in November 2003), the complete continuous monitoring data set for one monitoring site was lost. These issues are discussed in the general assessment of using continuous monitors in Chapter 8. Security issues arising from the early field trials include the threat of a controlled explosion when the anti-terrorist unit suspected that the monitoring equipment was a homemade explosive device. Equipment was clearly marked with contact details (at the risk of detection by vandals), as a result.

4.7.2 Collection and collation of Data

River flow, rainfall and quality data were collected over a period of 22 months as detailed in Tables 4.6 and 4.7. More information was gathered in September and November of 2003, to assess the current water quality conditions. Vandalism, theft, equipment availability, mechanical failure and Health and Safety considerations have

meant that all parameters and investigation methods could not reasonably be applied to all storm events monitored. The results obtained were, however, still valuable in demonstrating the consistency of monitoring methods, and the nature of urban runoff in the City.

i) Routine analytical data

Routine water quality information was supplied by the Environment Agency, and results of the analysis of spot samples were tabulated using the Agency's Water Quality Information Management System (WIMS).

None of the data sets were compatible, and could not be presented together in any of the software packages supplied. It was therefore decided to export information into Microsoft Excel for graphical and tabular representation, and for use in the SPSS statistics package. The historical General Quality Assessment database held by the Environment Agency for key river sites on the Rivers Sherbourne and Sowe was examined for information covering an initial period of seven years. (Table 3.1) and improvements in water quality, if any, (Environment Agency Water Quality reports, 1997-2003), identified for the catchments studied.

ii Rainfall data

Rainfall data was received as hard copy from Severn Trent Water as a text document, and was transferred into Microsoft Excel to allow graphical representation and statistical analysis as required.

4.8 Data production and presentation

Data from the quality monitor sonde was downloaded to desktop or laptop computer, and viewed and initially presented using Ecowatch version 3.12.10, developed by YSI Incorporated. The data were transferred to Microsoft Excel to allow comparison with other data sets. The flow data from the RMI Flowrat was downloaded to computer and

tabulated in Q-com for presentation in Q-view software developed by RMI of Canada. The software was difficult to use, and some aspects of the data could not be easily presented in the original format. Unfortunately the only distributor and software support service available in the UK ceased trading in 2000. Data were converted to Microsoft Excel format to allow direct comparison with quality data and for consistent graphical presentation. River level and flow data was obtained from the Environment Agency as text, and in Excel format. Information from the culverted watercourse investigations and the preliminary river quality work were grouped together and are presented, along with the post-remedial river investigation results, in Chapters 5, 6 and 7. Where measurements were made by a number of monitors at different sites during a single monitoring run, results were compared, in terms of peaks, troughs and concentrations recorded, to quality assure the data obtained. On some runs automatic samplers were used to obtain samples on an hourly basis, for analysis at the Environment Agency NAMAS accredited laboratory at Nottingham. The results of the analysis of samples were crosschecked against continuous monitor data (obtained at the same time), to confirm that the data collected was accurate. Calibration, cross calibration between units and a rigorous maintenance and probe replacement regime was applied to the use of continuous monitors throughout the period of this research to ensure a high level of consistency in results.

4.8.1 Statistical analysis

All results were collated for each investigation run and tested for the direction and strength of the relationship between two variables using Spearman's Rank Correlation. The variables may have been sampled parameters that were compared against each other, or against continuous data at a single monitoring site for different investigations, or involving the results from several sites during the same investigation. Using the null hypothesis that there is no relationship between two variables, Rs values were calculated

for each comparison with a result of –1, identifying a perfect negative correlation between two variables, and a result of 1 indicating a perfect positive correlation, therefore rejecting the null hypothesis. Where a result of 0 was calculated, the null hypothesis that there was no relationship between the two variables was accepted.

For each comparison;

$$Rs = 1 - \frac{(6\Sigma d^2)}{(N^3 - n)}$$

where; d = difference between two data ranks and n = number of ranks

The Rs values were presented in a series of tables for each phase of the research as detailed in Chapters 5, 6 and 7.

4.9 Conclusion

The extensive urban drainage system in Coventry includes several major culverts and underground watercourses that were potentially having a detrimental impact on water quality in the receiving River Sherbourne culvert, the River Sowe and River Avon. Routine analysis of the River Sherbourne by the National Rivers Authority, had identified that some urban stretches were failing to meet the required quality standards identified for the rivers under the River Ecosystem classification system (Section 2.4.3), and had deteriorated in quality compared to previous results obtained through the General Quality Assessment monitoring scheme (Section 2.4.2). Urban pollution can arise from urban runoff during storm conditions and from sewage misconnections, unsatisfactory sewer overflows, sewer blockages and illegal discharges, including trade effluent discharges as discussed in Chapter 2. These pollution sources may be difficult to trace through routine monitoring using spot sampling techniques (normally carried out during daylight hours to determine quality of river stretches up to 30 kilometres in length), at accessible sampling points, if pollutants are released on an intermittent basis

in culverted sections of watercourse or beneath the ground in extensive surface water drainage systems.

This research used continuous monitoring techniques to assess water quality pollution in culverted watercourses and drainage pipes, 24 hours each day, for periods of up to 2 weeks at a time. The technology was used to identify which watercourses were the most polluted, so that a focussed assessment of the severity, frequency and location of any polluting discharges could be made. The prioritisation exercise determined which watercourses had water quality problems against a benchmark class C watercourse (Sections 2.4.2 and 3.3). This method was used to identify stretches of underground culverts, and drainage systems, for the limited resources in the Environment Agency and in Severn Trent Water Ltd to address, in terms of effluent removal, sewer maintenance and, where necessary, enforcement action against those making illegal discharges.

The equipment proved very useful in identifying intermittent discharges and illegal cross connections, and could be easily moved to different locations within a drainage systems with minimal resource implications (Sections 4.3 and 8.1.1).

The use of continuous water quality monitors and automatic samplers in the open sections of the River Sherbourne, running as a culvert through the centre of Coventry, gave a real-time analysis of water quality in dry and wet weather periods that would identify the pollution problems caused by the operation of the six combined sewer overflows situated at Albany Road (Section 3.5). GQA data (Section 3.3) had previously identified the River Sherbourne as having relatively poor quality, but there was no indication of where the source of the problem was located, or whether there were a number of different reasons for the deterioration in water quality. The deployment of continuous monitors in open watercourses and culverted systems worked well to identify the conditions or time periods contributing to poor water quality, and assist in bringing about an improvement to the drainage systems responsible, and ultimately the

water quality itself. The targeted use of this technology in underground drainage systems has applications in all urban areas that are subjected to intermittent pollution problems, and is a cost effective way to identify the source of the pollutants to bring about an improvement in water quality in the receiving watercourses, as discussed in Chapter 8. The results of the monitoring surveys, and the conclusions drawn from these results are identified in Chapter 5, 6 and 7.

Chapter 5 - Phase 1 Results

Introduction

As identified in Section 4.3, pollution sources resulting in elevated total ammonium readings and depressed Dissolved Oxygen saturation, were highlighted at 4 locations in the River Sowe catchment;

1. The Swan Lane Culvert/ Gulson Road section
2. Springfield Brook culvert at the confluence with the River Sherbourne culvert
3. The River Sherbourne at Charterhouse immediately downstream of the City.
4. The Hall Brook culvert in the upper reaches of the River Sowe

This is the first of three Chapters discussing the results obtained from continuously monitoring these problem areas, to satisfy the aims and objectives identified in Chapter 1. The results are represented graphically to facilitate interpretation of peaks and troughs identified for ammonium (total ammonia), pH, SC and Dissolved Oxygen saturation, and identify whether the pollution sources were discharging on a continuous or intermittent basis. The results and conclusions for the investigatory runs on the Swan Lane/ Gulson Road drainage, the Springfield Brook culvert and the Hall Brook culvert during phase 1 are given in tables 5.1, 5.2 and 5.3. The results for the River Sherbourne investigations during the early, pre-remedial and post remedial stages of Phases 2 and 3, are discussed in Chapters 6 and 7, and summarised in Tables 6.1, 6.2 and 7.1. As pollution sources were identified and redirected to the foul sewer, or prevented from discharging by the Environment Agency, the monitors were moved to different monitoring locations, to investigate other problem areas as identified in Figures 5.1, 5.7 and 5.9.

5.1 Phase 1 – Problematic culverted watercourses in the River Sowe catchment

5.1.1 Swan Lane Culvert Catchment `and Gulson road surface water sewer

The Swan Lane culverted watercourse and Gulson Road surface water sewer were monitored between January 1999 and January 2000, as detailed in Section 4.3.1, and the results are given in Appendix 1, with a summary of findings presented in table 5.1, and Figure 5.1. Both systems outfall to the lower reach of the culverted section of the River Sherbourne.

The methodology and results for the investigation in Gulson Road surface water sewerage system and Swan Lane culverts (Figure 4.7) can be represented in a flow chart as given in Figure 5.1.

Figure 5.1. Methodology and Summary of results - Gulson Road Surface Water Sewer (SWS) and Swan lane culvert

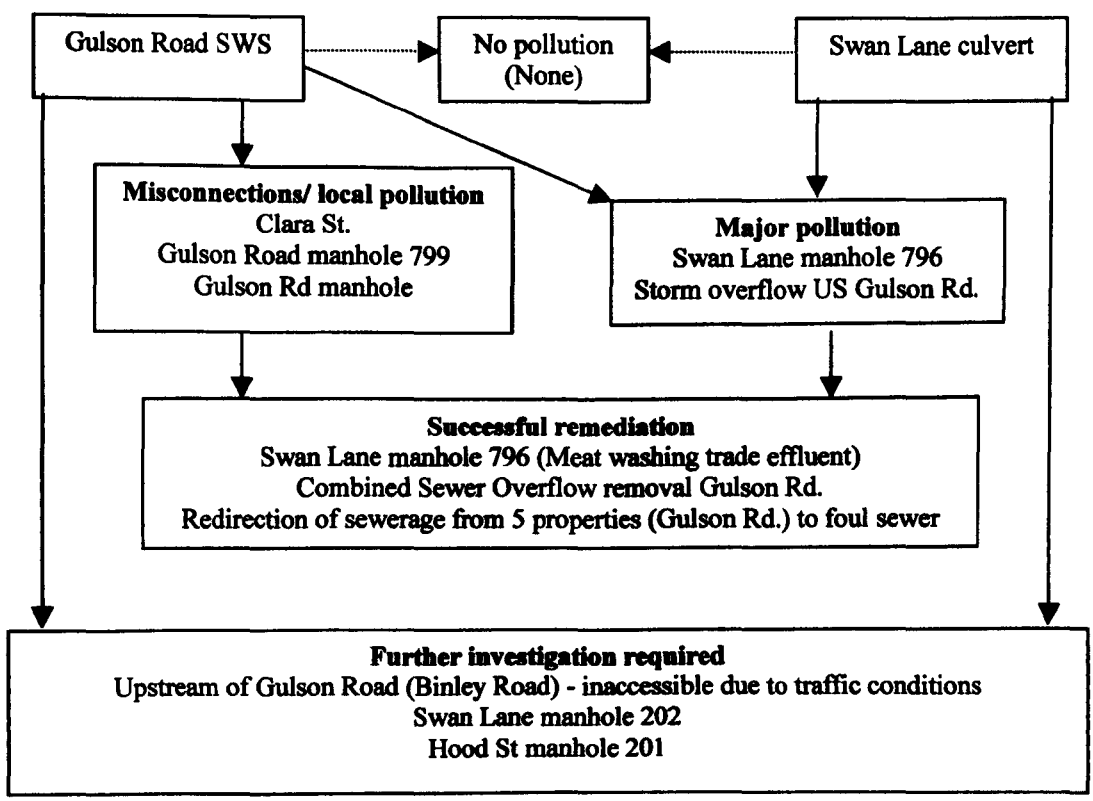


Table 5.1. Investigation into Water Quality in Swan Lane Culvert and Gulson Road Surface Water Sewer. Gulson Road SWS.

Date	Location	Results	Comments	Conclusions
Run 1 6/1/99 to 11/1/99	Top of Gulson road (manhole 799)	Average DO 90% saturation $NH_4^+(N)$ initially high during rainfall Average 2.5mg l^{-1} peak at 5mg l^{-1} on day 4 12:00 hrs	Low flow may have affected results $NH_4^+(N)$ level relatively high Peak during rainfall event The results are given in full in appendix 1.1	Rainfall impacted on results directly. More investigation needed along Binley Road but high risk (H&S) due to traffic and location of drainage system in road. Local pollution from misconnections suspected
Run 2 13/1/99 to 24/1/99	Clara Street	Diurnal pattern for SC and pH. $NH_4^+(N)$ max 6.5 mg l^{-1}	Peaks at 07:00 and 18:00 hours daily Extremely low flows at this point The results are given in full in appendix 1.2	Possible local misconnection Impractical to monitor further without modification because of low flows. CCTV survey required.
	Top of Gulson road (manhole 799)	$NH_4^+(N)$ max 2.7 mg l^{-1} DO minimum 75% saturation	23 January 20 January The results are given in full in appendix 1.2	Not a major pollution but sewage present More investigation needed on Binley Road by sewer gang.
	Gulson Road	SC peaks and pH fluctuation (6.8-8.5 pH) SC peaks coincident with rainfall peaks $NH_4^+(N)$ max 16.3 mg l^{-1} DO minimum 73% saturation	Peaks reflected incidence of storm events (7 in all). pH variation over 1.7 pH units 16:30 14/15 January storm event 16:30 14/15 January storm event The results are given in full in appendix 1.2	Pollution identified to a higher level downstream of manhole 799 Local investigation of identified stretch required **- Storm overflow detected by resultant camera survey** **- Misconnections from 5 properties identified. All foul sewerage from these properties redirected to the foul sewer.**

Key SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} milligrammes per litre. .Bold type indicates pollution source located

Table 5.1 Investigation into Water Quality in Swan Lane Culvert and Gulson Road Surface Water Sewer – Swan Lane Culvert

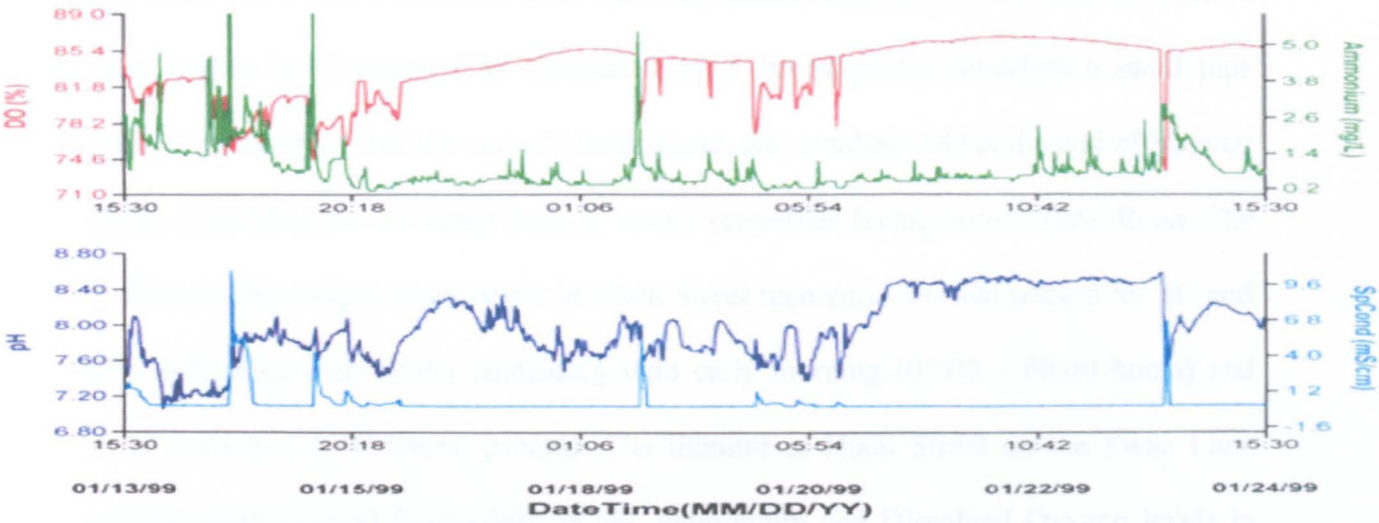
Date	Location	Results	Comments	Conclusions
Run 2 13/1/99 to 24/1/99 (continued)	Berry Street – Swan Lane culvert	Minimum pH value 5.5 pH units NH_4^+(N) and DO results reflect rainfall events but former may be a little high with peaks recorded at 50mg l^{-1}	This arm also takes side arm drainage Storm events identified The results are given in full in appendix 1.2	There is an indication of major organic pollution in the system above this point. More investigation needed
	Hood Street – Swan Lane culvert manhole 202	NH_4^+(N) average 2.4 mg l^{-1} NH_4^+(N) max 18.6 mg l^{-1} Other results at 6.20, 12.50 & 4.20 mg l^{-1} NH_4^+(N) DO and pH fell sharply with NH_4^+(N) rising to 20.0 mg l^{-1}	Fluctuations in line with storm events with increase in NH_4(N) and SC, and decrease in pH and DO. Last day of this investigation run The results are given in full in appendix 1.2	Possibility of a significant source impacting at or above this point More investigation needed Manhole 202 too close to junction from a H&S viewpoint. New location (MH 201) safer
Run 3 29/1/99 to 9/2/99	Swan Lane manhole 796	NH_4^+(N) max 1.08 mg l^{-1} SC peak each day DO probe failure	Peak at 01:00 Tuesday to Saturday Peak 01:00 Tuesday to Saturday Monitor covered in gristle/meat The results are given in full in appendix 1.3	Direct local polluting discharge to system. Regular peaks independent of rain events **Likely trade effluent**
	King Edward Road (side arm)	Rise in SC and ammonium peak to 7.2 mg l^{-1} DO fall as ammonium increased	Storm related peaks The results are given in full in appendix 1.3	Possibly as a result of organic matter washing through the system
	Berry Street	NH_4^+(N) max 1.08 mg l^{-1}	Storm event 8 February The results are given in full in appendix 1.3	Free of sewage at this time D/s of old overflow on sewer map
	Hood Street manhole 201	Poor ammonium results initially but reduced DO and increased NH_4^+(N) During prolonged rain event	Moved to manhole 201 for H&S reasons The results are given in full in appendix 1.3	Contaminated but requires further investigation when possible trade effluent has been removed
Run 4 7/2/99 to 26/2/99	Swan Lane manhole 796 Adjacent to Frederick Bird's Infant School	Large ammonium spike at 01:00 hrs to over 9mg l^{-1} on two occasions Dissolved Oxygen levels fell below 10 % saturation following major storm event on 21 February.	Single monitor was used to investigate drainage from wholesale market. Spike coincided with wash down operation and pumped trade effluent flow The results are given in full in appendix 1.4	**Discharge from meat processor at Barras heath market. System cleaned and effluent redirected to foul sewer**

Key SC – Specific Conductivity, DO – Dissolved Oxygen, NH_4^+(N) – Total ammonia (ammonium), mg l^{-1} milligrammes per litre. .Bold type indicates pollution source located

Table 5.1 shows that the first investigation (Run 1), between January 6 and January 11 1999 (Appendix 1.1), was undertaken using one continuous water quality monitor situated at manhole number 799 (Coventry Sewer Plans), at the top of Gulson Road. The surface water sewer was running with a low flow, and this may have affected the Dissolved Oxygen concentration, which averaged at around 90% saturation. The ammonium concentration was initially very high, but settled down to an average figure of around 2.5 mg l^{-1}. The ammonium results indicated (Table 5.1), that there was the potential for increased contaminant levels in the system, and it was decided to extend the monitoring run using a second monitor near the outfall. The nearby Gulson Road surface water system was also investigated using additional monitors, to give an overall assessment of pollutant discharge in this area. A second investigation (run 2, Table 5.1), started on January 13 1999, involved placing monitors at 5 sites on the Swan Lane culvert and Gulson Road surface water system. Barbed wire traps placed at Gulson Road surface water sewer, near the outfall to the culverted River Sherbourne, had previously collected sewer rags (foul sewage debris) on an infrequent basis, and the drainage system was subject to very high storm flows.

The results of the continuous monitoring runs are given as Appendix 1.2. Large ammonium peaks, of up to 16.3 mg l^{-1} at Gulson road and 20 mg l^{-1} at Swan Lane were identified, and at Gulson Road the measured pH fluctuated considerably over a range of 1.7 pH units (6.8 to 8.5 pH), and the conductivity probe clearly identified the major downpours, with peak concentrations recorded, as identified in Table 5.1, during the investigation. Each storm event (seven in all) affected the level of ammonium and Dissolved Oxygen saturation in the flow. An example of this is shown in Figure 5.2, where ammonium concentration increased to 16.3 mg l^{-1} at 16:30 hours on 14 January. The oxygen concentration fell to 73% saturation during a storm event on the same day.

Figure 5.2 Continuous monitor results for Gulson Road Manhole 799
13-24 January 1999



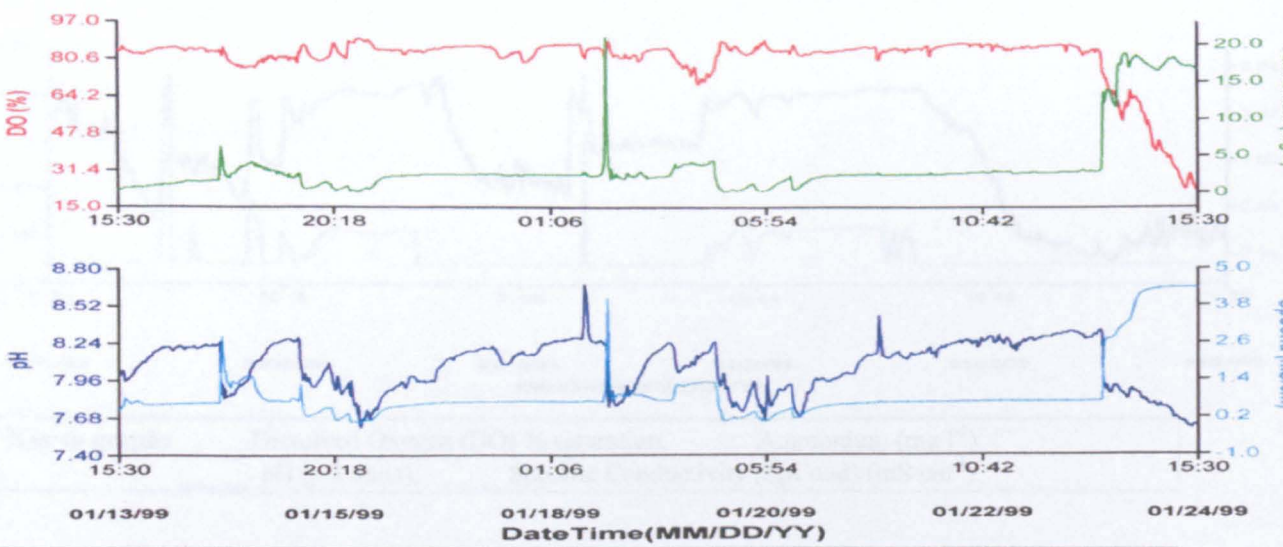
Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

The elevated ammonium results suggested that there was a potential foul sewage source in the vicinity of the monitoring point requiring further investigation. A drainage area investigation, by Coventry City Council, later identified an unknown foul sewer overflow connecting between the foul sewer and the surface water system. This had previously been identified for removal in 1963, as part of the Sowe Valley sewerage scheme (Chapter 3).

At the top of Gulson Road the monitor showed similar results to that of the downstream monitoring site near the outfall, as shown in Table 5.1. The recorded pH fell with each increase in flow and the ammonia concentration increased, with a maximum figure of 2.7 mg l^{-1} recorded on 23 January (Figure 5.3). Dissolved Oxygen levels were higher than expected, which may reflect periods of low flow, but these dropped to around 75% saturation during a storm event on 20 January. Despite the fluctuation in results recorded, the barbed wire traps had not previously collected any debris at this point, the ammonium levels were relatively low, and it was not conclusive that the contamination at this point was from a direct foul sewage discharge. It was thought that misconnections

from the surrounding residential areas were the cause of the water quality fluctuations at this point, but it was considered to be relatively minor, and identified for possible future investigation by Coventry City Council. Further investigation identified a small pipe between manhole 582 at the end of Monks Road, and manhole 584 at the end of Botoner Road, containing the sewerage from at least 5 properties facing onto Gulson Road. The monitor in the surface water sewer at Clara Street recorded a diurnal pattern for SC and pH, with twice-daily peaks coinciding with early morning (07:00 – 08:00 hours) and early evening (18:00 hours) periods. The monitor at Hood Street on the Swan Lane culvert again showed fluctuations in pH, ammonium and Dissolved Oxygen levels in line with known storm events, as shown in Figure 5.3:

Figure 5.3 Continuous monitor results for Swan Lane Culvert at Hood Street 13-24 January 1999

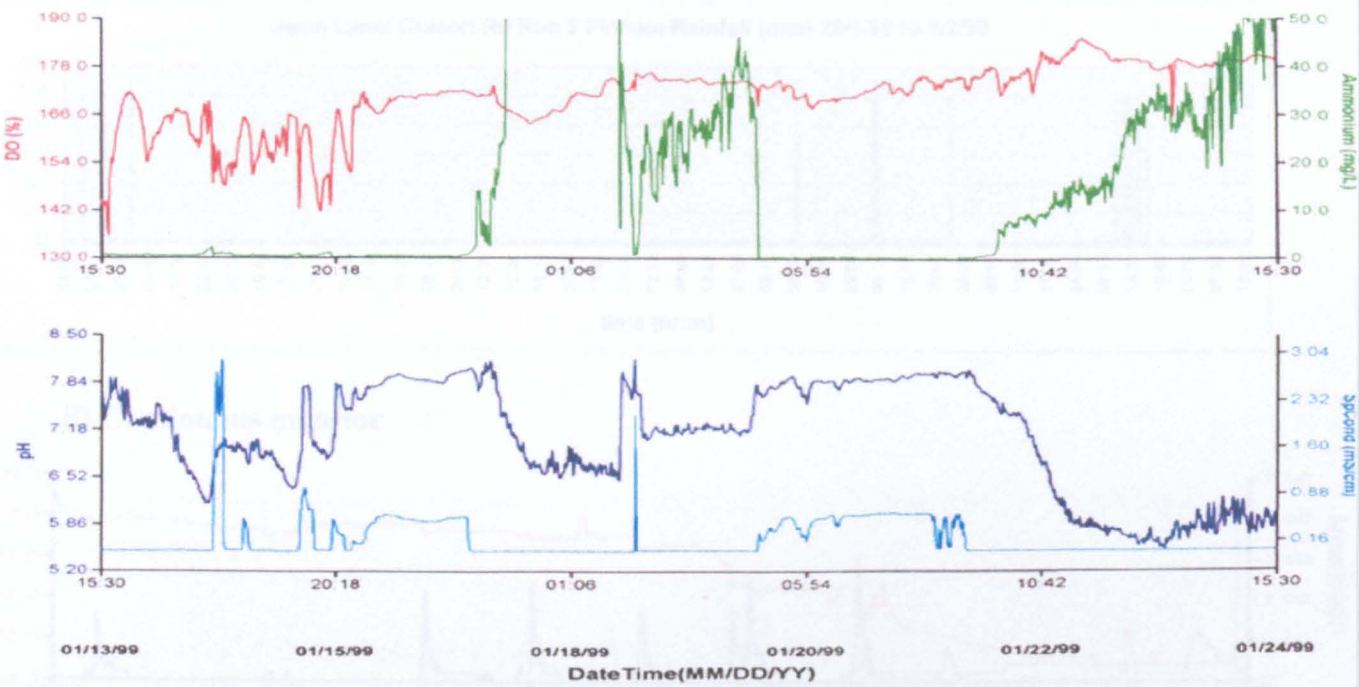


Key to graph: ____ Dissolved Oxygen (DO) % saturation, ____ Ammonium (mg l^{-1})
____ pH (pH units), ____ Specific Conductivity (SpCond) (mS cm^{-1})

The results for this site are summarised in Table 5.1. This site was the closest point monitored to the River Sherbourne culvert, with increases in ammonium to a maximum concentration of 18.60 mg l^{-1} during the investigation period. During the last day at this site the pH and Dissolved Oxygen concentration fell sharply, while the ammonium rose to almost 20 mg l^{-1}. SC also increased at the same point of the investigation. The other

monitor at Berry Street also showed fluctuations in pH, SC and ammonium concentration at this time, indicating the possibility of a significant source at this point. There was a need to investigate upstream of this point, to determine whether a traceable source could be identified. The ammonium and Dissolved Oxygen probes showed fluctuations in line with rainfall events, consistent with the Hood Street monitor, and pH levels fell to a minimum of 5.5 pH units, as shown in Figure 5.4:

Figure 5.4 Continuous monitor results for Swan Lane Culvert at Berry Street 13-24 January 1999



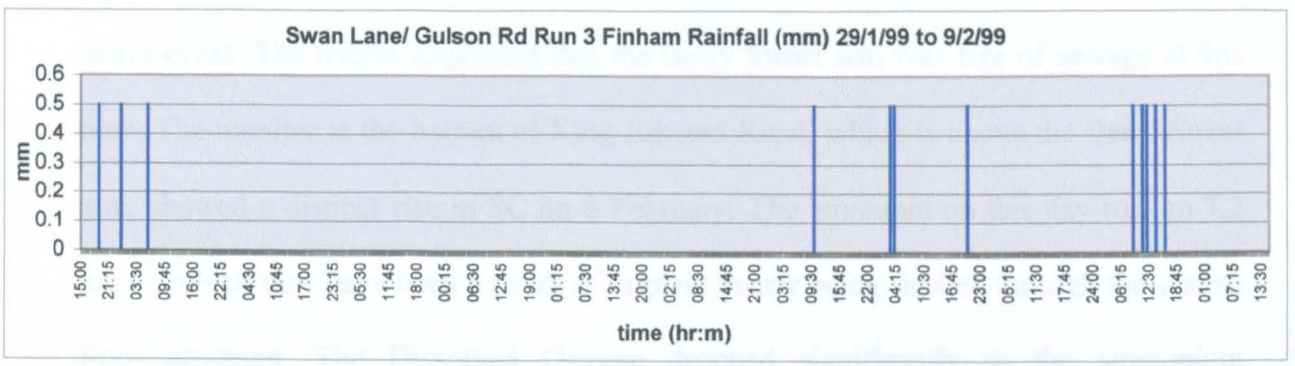
Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

There was clearly a major contamination source above this point that required further investigation. Between January 29 and February 9 1999, a single monitoring run was undertaken on the Swan Lane Culvert using 3 YSI 6000 monitors. Data from the monitor placed in the main culvert on Swan Lane showed a significant regular peak of ammonium occurring at 01.00 each day, from Tuesday to Saturday. The Dissolved Oxygen probe displayed an error in the concentration of dissolved saturation, but a

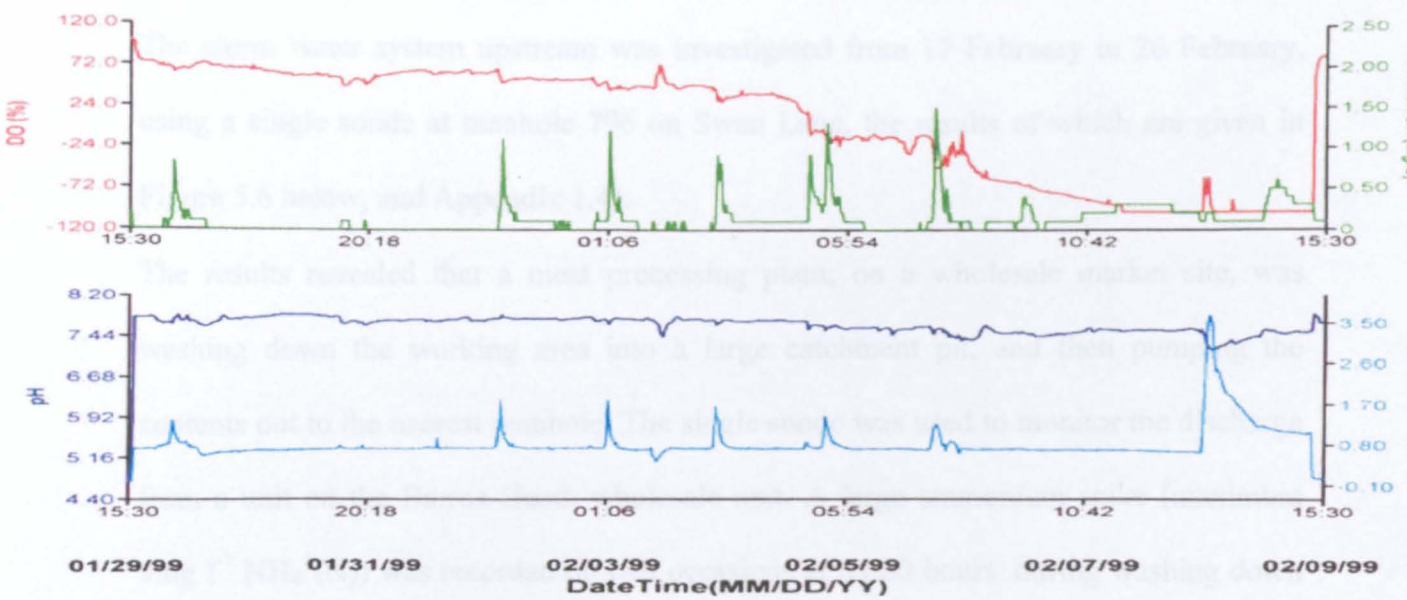
relative reduction in Dissolved Oxygen, during the second set of rainfall events, was displayed during this run at Swan Lane, and for the probe with similar calibration problems at Hood Street (manhole 201), as shown in Appendix 1.3. The conductivity measurements at Swan Lane showed peak values between 01:00 and 01:30 hours from 2 to 6 February, in line with the ammonium peaks, as shown in Figure 5.5:

Figure 5.5 Finham rainfall and continuous monitor results for Swan Lane Culvert at Swan Lane 13-24 January 1999

i) Rainfall



ii) Continuous monitor



Key to graph: ____ Dissolved Oxygen (DO) % saturation, ____ Ammonium (mg l^{-1})
____ pH (pH units), ____ Specific Conductivity (SpCond) (mS cm^{-1})

The results showed a regularity in peak concentrations for SC and ammonium during the dry weather period, that indicated a regular and intermittent direct discharge to the system, rather than the product of an overflow or instrument error. Daytime spot sampling at the outfall would not have identified this intermittent discharge, and when the monitor was retrieved from this run, it was covered in what appeared to be pieces of meat and gristle. The monitor on Berry Street showed a low concentration of ammonium that peaked to only 1.08 mg l^{-1} during the storm event on 8 February, and a good level of Dissolved Oxygen saturation was maintained, which only dipped slightly during the storm event. The results suggested that the Berry Street arm was free of sewage at this time. The monitor at the bottom of King Edward Road, which is above the Berry Street arm, showed a distinct rise in SC on 8 February. The ammonia on this day rose to 7.2 mg l^{-1}, which may have been a result of organic matter being flushed through the system from upstream. The Dissolved Oxygen dropped significantly as the ammonium concentration increased.

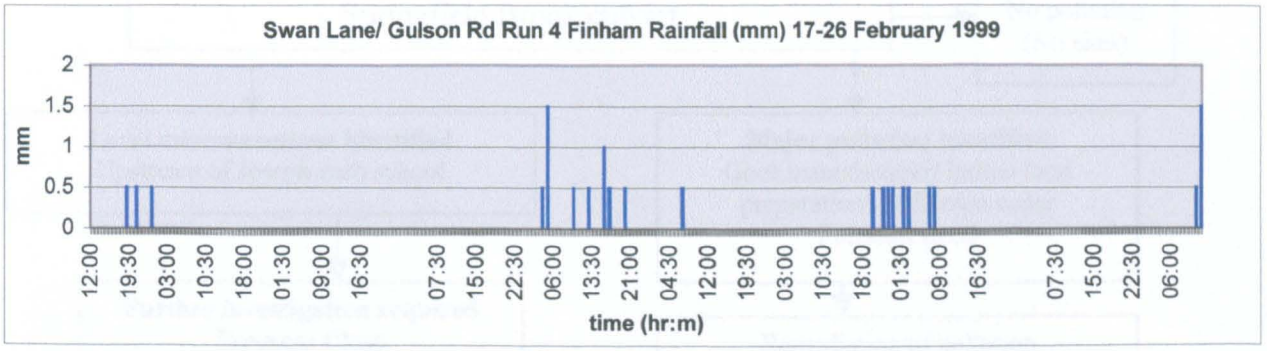
The storm water system upstream was investigated from 17 February to 26 February, using a single sonde at manhole 796 on Swan Lane, the results of which are given in Figure 5.6 below, and Appendix 1.4).

The results revealed that a meat processing plant, on a wholesale market site, was washing down the working area into a large catchment pit, and then pumping the contents out to the nearest manhole. The single sonde was used to monitor the discharge from a unit on the Barras Heath wholesale unit. A large ammonium spike (maximum 9mg l^{-1} $NH_4^+(N)$) was recorded on two occasions at 01:00 hours, during washing down operations at the unit. The cleaning operation was carried out at 23.00 each day, from Tuesday to Saturday, and all effluent was pumped to a manhole within the factory curtilage. This manhole was connected to the storm water system of the wholesale

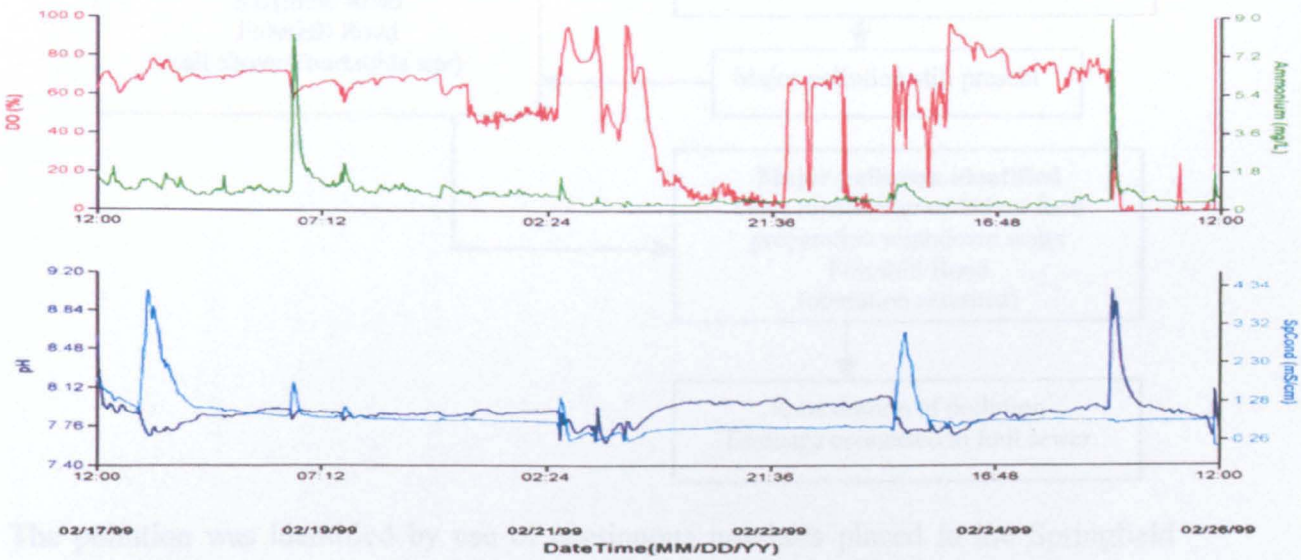
market, which was, in turn, connected to the public storm water system. The system was cleaned the following day, which gave rise to more ammonium peaks, and a reduction in Dissolved Oxygen. The effluent was re-directed to the public foul water sewer.

Figure 5.6 Finham rainfall and continuous monitor results for Swan Lane Culvert at Swan Lane 17-26 February 1999

i) rainfall



ii) continuous monitor results

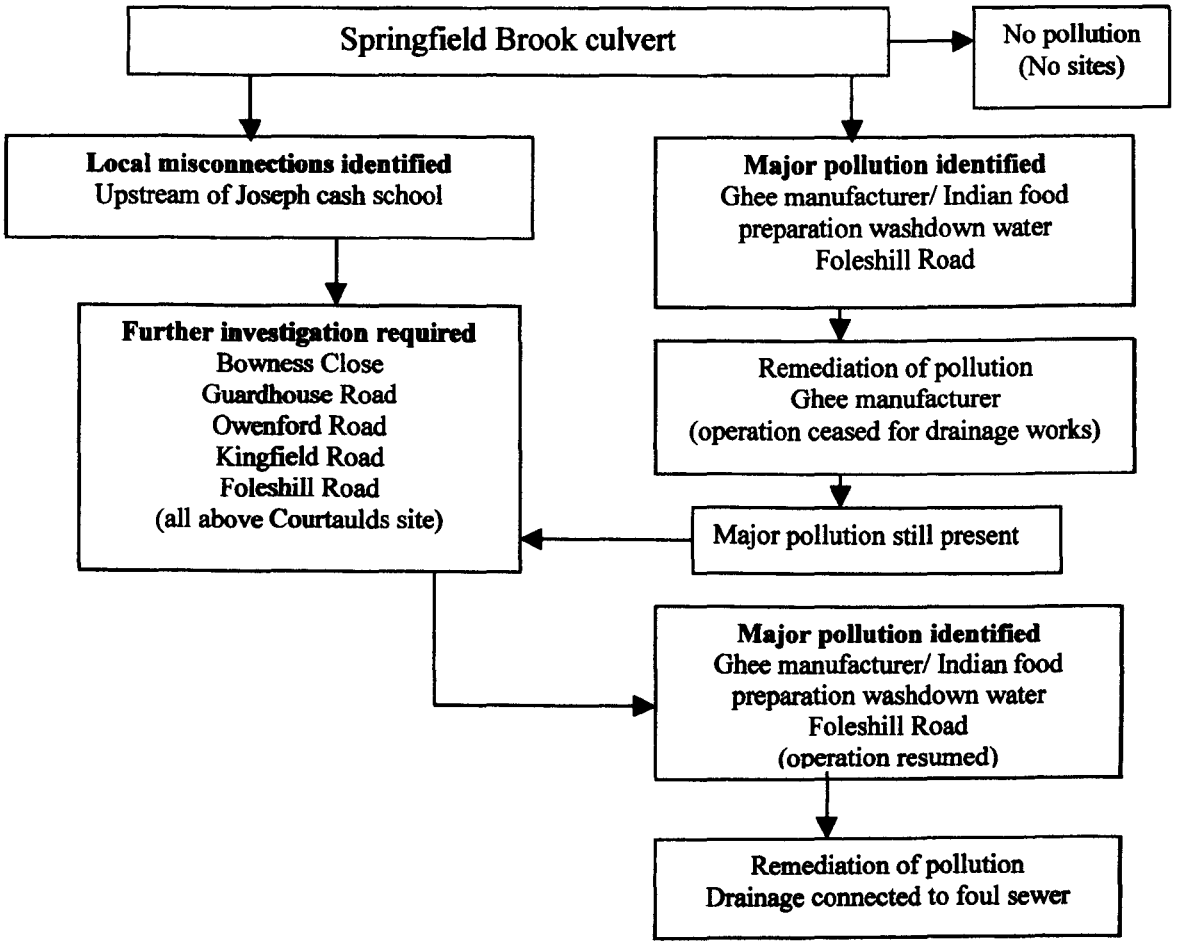


Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

5.1.2 Springfield Brook Catchment

Seven monitoring runs were undertaken on the Springfield Brook between December 1997 and April 2001, as detailed in Section 4.3.3. The results are summarised in Table 5.2 and Figure 5.7.

Figure 5.7 Methodology and summary of results - Springfield Brook culvert



The pollution was identified by use of continuous monitors placed in the Springfield Brook culvert, as identified in Figure 4.8. The major pollution arising from a trade effluent discharge on Foleshill Road, which was detected as a result of high ammonium concentration and low Dissolved Oxygen saturation, was due for immediate removal but connection to the foul sewer was delayed and the discharge recommenced. This was discovered only by the fact that the pollution was again identified using the continuous water quality monitors.

Table 5.2 Investigation into Water Quality in Springfield Brook.

Date	Location	Results	Comments	Conclusions
12/12/97 to 2/1/98 run 1	Bowness Close	$NH_4^+(N)$ max 4.7 mg l^{-1}(16:25 hrs 17/12) Also 2.9 (04:27 hrs 17/12) and 3.1mg l^{-1} (05:00 hrs 18/12) DO 38.9, 35.8 and 42.5 % saturation at these times. The results are given in full in appendix 2.1	3 $NH_4(N)$ peaks during 17 & 18 December with DO falls and increased conductivity following a major storm. (8.5 mm in 19 hours) Low DO readings Monitor drift at end of run.	Readings confirmed by monitor at School imply unknown pollution source locally. Possible trade effluent. Shallow drainage. Some storm effects
	Christopher Cash School	$NH_4^+(N)$ max 3.2 mg l^{-1}(15:00 hrs 17/12) Also 2.9 (04:00 hrs 18/12) and 3.1mg l^{-1} (14:03 hrs 18/12) DO 58.2, 50.3 and 39.3 % saturation at these times. The results are given in full in appendix 2.1.	3 $NH_4(N)$ peaks identified, as above. DO reduced in line with ammonium and spec. cond. peaks Time of travel between 2 points may indicate storage capacity in both foul and storm sewers. Monitor drift at end of run	Further investigation required on this system. – impractical with monitors. Low fall on drainage system and low flows. Impact during rain but no major sewage overflow suspected.
	Courtaulds site	$NH_4^+(N)$ 7.96 mg l^{-1}(22:24 hrs 17/12) Also 8.33 (08:42hrs 18/12) and 12.4 mg l^{-1} (23:42 hrs 19/12) DO minimum at around 65- 68% The results are given in full in appendix 2.1.	Initial ammonium peaks not considered. Low flow. Settled down before storm event. Storm related fall in DO and rise in $NH_4^+(N)$	$NH_4^+(N)$ initial peak may be first flush effect be due to low flow conditions in culvert. Further rain storms did not impact. Suspect low level continuous discharge Side-arm samples taken but too dangerous to monitor.
	Cash's Lane	$NH_4^+(N)$ max 3.2 mg l^{-1} 17- 18 December. DO minimum 0.5% saturation The results are given in full in appendix 2.1.	DO drop for 20 hours and 29 minutes before recovery. Storm event had major impact here. A discharge between school site and Cash's Lane is suspected	**Investigation using sewer gang identified trade discharge from Indian foods manufacture**
	Planet Carpark	Probes malfunction after initial storm but relative increases displayed in each rain event for $NH_4^+(N)$ The results are given in full in appendix 2.1.	Disregard results. Suspect calibration of monitor or damage following first storm	Casing breached/ damaged but some indication of increased ammonium levels during each storm event

Key SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} milligrammes per litre. Bold type indicates pollution source located

Table 5.2 Investigation into Water Quality in Springfield Brook.

Date	Location	Results	Comments	Conclusions
2/3/98 to 9/3/98 run 2	Courtaulds site	NH_4^+(N) max 12 mg l^{-1} 5 march The results are given in full in appendix 2.2	Significant ammonium peak before Finham rainfall event on the afternoon of the 5 March.	Pollution source remains upstream of Courtaulds' site High peak may indicate local rainfall on impermeable surface before Finham measurement or increase in continuous source
	Cash's Lane	No significant ammonium peak DO started at 40% saturation. 4 reported sags with minimum 50% The results are given in full in appendix 2.2.	Results much improved at Cash's Lane following cessation of trade effluent from Indian food business	Some dilution from canal weir immediately downstream of Courtaulds
	Springfield Place	3 NH_4^+(N) peaks - max 33 mg l^{-1} The results are given in full in appendix 2.2.	Suspect grossly polluted watercourse or foul sewer overflow	Further investigation required
24/3/98 to 2/4/98 run 3	Courtaulds site	Initial peak of 80mg l suspect. Peaks to 25mg l^{-1} NH_4^+(N) follow. Dissolved Oxygen dropped to 58% saturation The results are given in full in appendix 2.3.	Ammonia drift occurs towards end of run following major storm event on 9 April	Post trade effluent cessation. May be intermittent now.Results still indicate a source, possibly overflow derived, upstream of Courtaulds' site
	Springfield Place	Variable ammonium result to max of 167 mg l^{-1}.consistently >40mg l^{-1} DO fell to 0% saturation The results are given in full in appendix 2.3.	Results again indicated either a grossly polluted watercourse or a foul sewer	**Identified as a foul sewer**.- useful as background data. Some rainfall impact from combined drainage. Culvert manhole located nearby
	Planet Carpark	Ammonium levels suspect initially with max 16.0 mg l^{-1} following storm 25- 26 March. DO levels reduced to average of 45% saturation after 25 March The results are given in full in appendix 2.3.	May be low flows causing probe drift initially or algal effects from canal overflows at Courtaulds and Matlock Road upstream	**Further investigation required. System may still be polluted with sewage or other organic source**

Key SC – Specific Conductivity, DO – Dissolved Oxygen, NH_4^+(N) – Total ammonia (ammonium), mg l^{-1} milligrammes per litre. Bold type indicates pollution source located

Table 5.2 Investigation into Water Quality in Springfield Brook.

Date	Location	Results	Comments	Conclusions
29/7/98 to 2/8/98 run 4 29/7/98 to 8/8/98 run 4	Courtaulds site	$NH_4^+(N)$ max 36 mg l^{-1} 31 July 18:00 hours following increased levels from 12:30 hours DO dropped to 46% saturation at around 10:00 in coincidence with SC peak and pH fluctuation The results are given in full in appendix 2.4.	Short run over 4 days. Ammonium peak coincided with pH fall and followed spikes in SC and Dissolved Oxygen drop	Contaminant upstream of Courtaulds site requires further investigation. Peaks are either due to storm overflow or first flush effect from storage in low gradient system.
	Cash's Lane	$NH_4^+(N)$ max 5.5 mg l^{-1} 4 to 5 August Do fell to 0% repeatedly during the run PH dropped towards end of run to around 4 pH units The results are given in full in appendix 2.4.	Cessation of trade effluent was temporary. Following advice from local MP Indian food manufacturer had started discharging to sewer again without notification	Trade effluent had continued to impact on system at Cash's Lane
14/8/98 to 24/8/98 run 5	Courtaulds site manhole 891	$NH_4^+(N)$ max 247 mg l^{-1} 20 August PH fluctuation coincided with conductivity peak and DO fall The results are given in full in appendix 2.5.	Unreliable $NH_4^+(N)$ results. May indicate relative presence of ammonium following rain events	Some impact from rain events on 20 and 23 August
	Cash's Lane	$NH_4^+(N)$ results show probe drift PH fluctuation coincided with conductivity peak and DO fall The results are given in full in appendix 2.5.	Unreliable $NH_4(N)$ results	Some impact from all rain events
	Springfield Place manhole number 6999	$NH_4^+(N)$ max 13.5 mg l^{-1} 20 August The results are given in full in appendix 2.5.	High ammonium readings and corresponding fall in DO	Some impact from all rain events
	Planet Carpark	Poor results obtained The results are given in full in appendix 2.5.	Low flow at this chamber	Unreliable results after first rainfall event in minimal flow

Key SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} milligrammes per litre. Bold type indicates pollution source located

Table 5.2 Investigation into Water Quality in Springfield Brook.

Date	Location	Results	Comments	Conclusions
23/3/01 to 10/4/01 run 6	Dicken's Road	Regular ammonium peaks and extensive fluctuation in all other determinands The results are given in full in appendix 2.6.	Too erratic for storm water system Some variation due to rainfall shows combined or ingress component	**Identified as foul sewer** not storm water sewer
	Borrowdale Close	$NH_4^+(N)$ max 33 mg l^{-1} 7 April The results are given in full in appendix 2.6.	Good correlation between data and storm events after April 3. Ammonium may be relative as base level high	Storm related pollution or wash-through of misconnection requires further investigation
	Guardhouse road	$NH_4^+(N)$ max 120 mg l^{-1} 3 April The results are given in full in appendix 2.6.	Suspect result. Ammonium may be relative as base level high	Storm related pollution or wash-through of misconnection requires further investigation
	Owenford Road	$NH_4^+(N)$ max 120 mg l^{-1} 5 April The results are given in full in appendix 2.6.	Good storm correlation after 3 April for all parameters	Storm related pollution or wash-through of misconnection requires further investigation
	Kingfield Road	DO saturation fell to below 10% a number of times after 3 April The results are given in full in appendix 2.6.	Good storm correlation after 3 April for all parameters	Storm related pollution or wash-through of misconnection requires further investigation
	Cash's Lane	Maximum ammonium peaks at 2.0 mg l^{-1} or less Dissolved Oxygen saturation above 65% The results are given in full in appendix 2.6.	Good results for this period which show a marked improvement in water quality.	Previous trade effluent problem now removed and water quality improved
	Planet carpark	Initial $NH_4^+(N)$ peak of 8 mg l^{-1} followed by lesser peaks with maximum 5 mg l^{-1}. The results are given in full in appendix 2.6.	Good storm correlation after 3 April for all parameters	Low flow conditions at site gave high $NH_4^+(N)$ levels which then settled

Key SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} milligrammes per litre. Bold type indicates pollution source located

During a monitored storm event from 12 December to 2 January, the ammonia concentration showed an increase at Bowness close and Christopher Cash Junior School, with concentration peaks of 6.1 and 9.2 mg l^{-1} respectively as shown in Table 5.2. Specific Conductivity also peaked during the event, and pH levels dropped slightly. Oxygen levels dipped at Christopher Cash Junior School, but the probe failed at Bowness Close. An increase of ammonia, not related to a storm event, was identified at 14:30 hours on 18 December at Bowness Close, and 03:15 on 19 December at the School (approximate time difference 12.75 hours). The SC did not increase, and there was no explanation identified for the anomaly. The monitor at Courtaulds and Cash's Lane showed increased ammonia concentrations, with the latter peaking at 21.97 mg l^{-1}. Dissolved Oxygen saturation declined to 0.5 % during a storm event on 18 December, as shown in Figure 5.8 below, and Appendix 2.1.

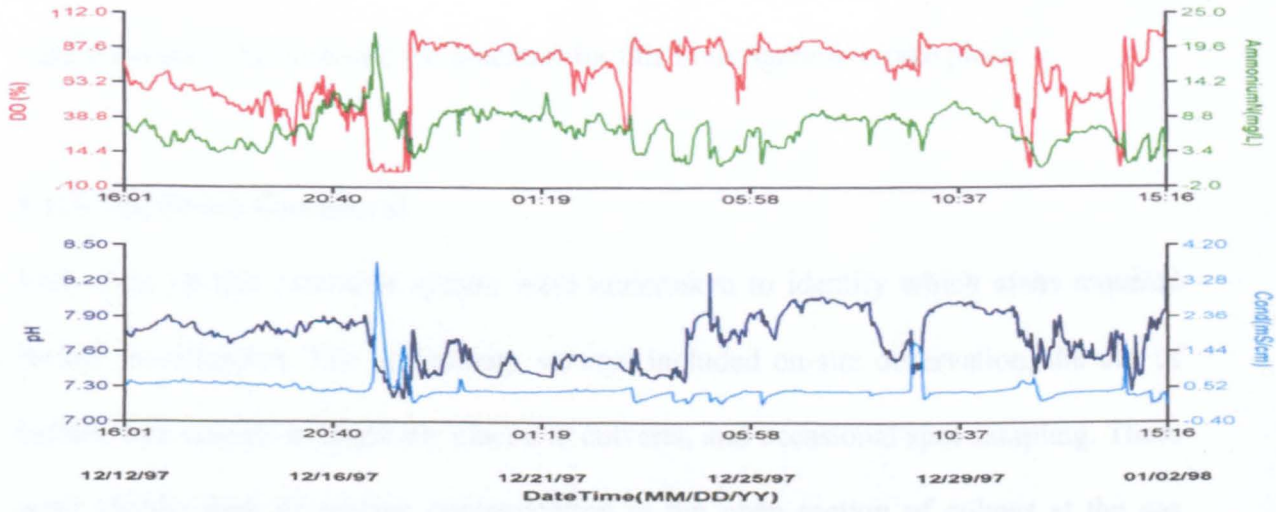
The monitor at the Planet car park showed an apparent probe failure for Dissolved Oxygen following the storm event, and erratic measurements for ammonia at all other times. This was later found to be a foul sewer chamber next to the storm water culvert. It was concluded however from the results, that between Christopher Cash Junior School and Cash's Lane there was significant ammonia input, requiring further investigation.

The results for the monitoring site at Cash's Lane between 29 July 1998 and 8 August 1998 (Appendix 2.4) show some diurnal pattern to the Dissolved Oxygen, ranging between 0% and 95% with elevated ammonium concentrations up to 5.0mg l^{-1} NH_4^+(N).

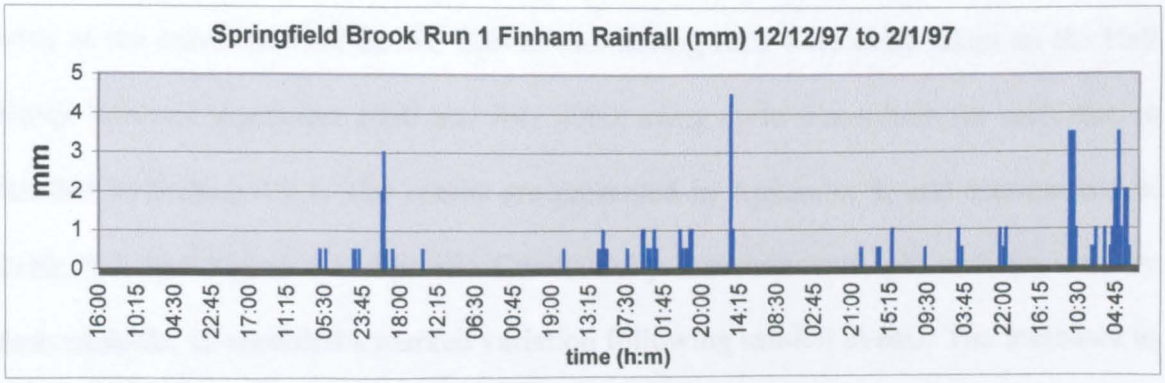
The monitoring point upstream showed that the Springfield Brook was generally consistently good in quality above this point. Further investigations of the culverted watercourse and surface water system in this area, revealed a foul sewer draining the kitchen and toilets of an Indian restaurant and sweet manufacturer, which had been misconnected to the storm water system. A spot sample taken of the offending drainage

system showed a BOD of 1350 mg l^{-1}, and an ammonium concentration of 3.5 mg l^{-1}. Coventry City Council's Environmental Health Officers were informed and work commenced immediately to request removal of the polluting discharge.

Figure 5.8 Continuous monitor results for Cash's Lane and Finham rainfall from 12 December 1997 to 2 January 1998.



Key to graph: ____ Dissolved Oxygen (DO) % saturation, ____ Ammonium (mg l^{-1})
____ pH (pH units), ____ Specific Conductivity (SpCond) (mS cm^{-1})



The work to remove the pollution was somewhat delayed for a number of reasons, and the impact was again shown in the monitoring runs during the summer of 1998. All monitoring work on the culverted watercourse was suspended until the misconnection was removed. An extensive run carried out between 23 March and 10 April 2001, (after the discharge had finally been removed), showed an improvement in the water quality of

the lower reaches of the Springfield Brook culvert (Appendix 2.6). Ammonia levels at Cash's Lane became more consistent with peaks (although still present), of less than 2 mg l^{-1}. The quality at Kingfield Road and above remains poorer than experience would dictate, and may require further investigation of industrial and commercial sites upstream of this point. The removal of resources to maintain the monitoring capability used previously, has reduced the potential for this investigation to take place.

5.1.3 Hall Brook Catchment

Early runs on this extensive system were undertaken to identify which areas required further investigation. The preliminary surveys included on-site observation, the use of barbed wire strands strategically placed in culverts, and occasional spot sampling. There were visible signs of sewage contamination in the open section of culvert at the gas works, and the barbed wire traps identified that intermittent discharges containing sewer rags, that warranted further investigation, were present in both the Hen Lane and Dunlop arms of the culverted Hall Brook. Eleven monitoring runs were undertaken on the Hall Brook between September 1998 and July 2000, using up to 6 monitors for each run, as detailed in Section 4.3.1. The results are presented in Appendix 3, and summarised in Table 5.3, and Figure 5.9. Specific Conductivity measurements, pH and the sanitary determinands, all recorded a marked variation following rainfall events. The increases in ammonium, and reductions in pH, SC and Dissolved Oxygen saturation, though slight, demonstrate an initial high strength flush followed by a return to pre-storm levels.

Table 5.3 Investigation into Water Quality in Hall Brook.

Date	Location	Results	Comments	Conclusions
2/9/98 to 12/9/98 run1	St Paul's cemetery manhole 650 (Dunlop arm)	Problem with ammonium probe pH fell to 6.3 following storm event The results are given in full in appendix 3.1	Preliminary run. low flows pH drop following each storm event	Further investigation required
	Kirkdale Avenue manhole 913 (Hen Lane arm)	NH_4^+(N) peaks to 0.7 mg l^{-1} during each rain event The results are given in full in appendix 3.1	Shallow site. Alternate site sought. pH increase following storms	Further investigation required Some signs of NH_4^+(N) contamination. pH increase may indicate local domestic source
	Foleshill gasworks – open stretch (downstream of both arms)	pH peaks identified DO fell to 36.4% The results are given in full in appendix 3.1	Sewage debris present Deterioration in Dissolved Oxygen levels following storms pH increase as on Kirkdale Ave	Signs of sewage debris upstream on metalwork. Further investigation required
23/9/98 to 3/10/98 run2	Hen Lane manhole 052	Diurnal peaks occurred late afternoon in ammonium and pH. ammonium max > 11 mg l^{-1} Storm event reduced pH to 7.1 The results are given in full in appendix 3.2	High ammonium result in dry weather indicates misconnected or broken foul drainage system or trade effluent	Suspect sewage source in vicinity or washed through in storm event. Further investigation required
	Marshdale Avenue – manhole 115 (Hen Lane arm)	Ammonium probe problem following storm events. The results are given in full in appendix 3.2	Results seem poor due to low flows yet reflect storm events	Further investigation required. Better site located on Marshdale Ave at mh 114
	Marshdale Avenue – Dunlop arm Manhole 113	Variable ammonium results with max 1.0 mg l^{-1} peak The results are given in full in appendix 3.2	SC readings good following storm event	Inconclusive result. Further investigation required
	A444 manhole 143	Unreliable NH_4^+(N) results after storm event The results are given in full in appendix 3.2	Difficult site to monitor for H&S reasons. Very shallow wide culvert at this point.	Inconclusive result. Further investigation required using different monitoring point
	Doyle Drive at outfall to River Sowe	SC dipped rather than increased during storm event. The results are given in full in appendix 3.2	Possible impact of canal overflow at this point	Storm incidents reflected in results

Key to Table: SC – Specific Conductivity, DO – Dissolved Oxygen, NH_4^+(N) – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 5.3 Investigation into Water Quality in Hall Brook.

Date	Location	Results	Comments	Conclusions
16/10/98 to 26/10/98 run3	Lythalls Lane manhole 971	Initial NH_4^+(N) results off scale during continued rain event with peak at 16.9 mg l^{-}. Spikes of around 7 mg l^{-} recorded in dry weather. Initial pH peak of 10.5 recorded. DO saturation very low following initial storm event and remained so. The results are given in full in appendix 3.3	Ammonium peaks reflect wet weather conditions although peak value in dry weather on 20 October preceded storm event measured at Finham. Sewer rags continued to show in flow between storm events.	Chemical or local sewerage source suspected with first flush measured or trade effluent component. The pH result may confirm this. Pollution suspected. Further investigation essential
	Marlisa Drive (industrial estate side arm)	Low levels of ammonium recorded except for peak on 19 October. pH readings low. Monitor stained with oil. The results are given in full in appendix 3.3.	Unusually low pH readings and storm related data Previous trade effluent misconnection identified at these industrial units. May be more now at other sites	Industrial estate requires further monitoring and drainage survey. Possible trade effluent connection and first flush effect following storms. Oil present in flow
	Marshdale Avenue Dunlop arm manhole 113	Ammonium results suspect. Dissolved Oxygen, and SC data reflect storm events. pH decreases during storms The results are given in full in appendix 3.3.	Inconclusive result	Further investigation required
	Hen Lane manhole 052	All probes showed drift or inactivity following final storm. No NH_4^+(N) variation detected during run. Result suspect. The results are given in full in appendix 3.3.	Disappointing NH_4^+(N) results.	Suspect casing breached during final storm events on 23- 24 October (up to 3.5 mm per hour during each event). Foam strips added to casings.
	Marshdale Avenue, colliery sidings manhole 115 (Hen Lane arm)	Poor Dissolved Oxygen levels following light continuous rain events increasing during larger storm events. Minor NH_4^+(N) peaks to 0.2 mg l^{-1}. The results are given in full in appendix 3.3.	Initial pH peak to 10.0 during initial rain event	Further investigation required.

Key to Table: SC – Specific Conductivity, DO – Dissolved Oxygen, NH_4^+(N) – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 5.3 Investigation into Water Quality in Hall Brook.

Date	Location	Results	Comments	Conclusions
5/8/99 to 15/8/99 run 4	Lythalls Lane Manhole 971 (side arm to culvert)	Ammonium results at this site much reduced with peaks to a maximum of 1.69 mg l^{-1} between the rain events on 6 and 9 August. The Dissolved Oxygen probe showed gradual decline over run period giving unsatisfactory results The results are given in full in appendix 3.4.	**Misconnection from a Nursing home identified. All foul sewage connected to the storm system was redirected to foul March 1999.**	Still some rain related organic contamination but the main source has been removed with the removal of the Nursing home misconnection.
	Hall Brook at Marlisa SWS Discharge	Results showed a non-storm related $NH_4^+(N)$ peak of 7 mg l^{-1}. Dissolved Oxygen variation decreased as did the level of oxygen saturation following the second storm event The results are given in full in appendix 3.4.	The non storm related ammonium peak again points to a trade effluent, broken sewer pipe or domestic discharge through misconnection	**This contamination was found to be the result of discharged washing down liquors at a small pet food factory**
	Marshdale Avenue – manhole 113 Dunlop arm	Dissolved Oxygen levels were further depleted but followed the same general pattern as the upstream site after the second rainfall event. $NH_4^+(N)$ peaks were <2 mg l^{-1}. The results are given in full in appendix 3.4.	Good results showing the impact of local pollution and rainfall events in this section of the culverted watercourse.	Ammonia increases at this site were attributed to the activities of a unit on Marlissa Drive as identified above, though some sewage debris is still being detected at this site
	Hen Lane manhole 052	A number of minor $NH_4^+(N)$ peaks relating to storm events were recorded. The results are given in full in appendix 3.4.	Oxygen saturation at this site is generally lo at 50-70% saturation.	Some signs of possible sewage contamination in the system relating to rainfall or first flush effect
	Marshdale Avenue– manhole 114	Dissolved Oxygen levels at this site remained constant at around 82% saturation with $NH_4^+(N)$ peaks of less than 1 mg l^{-1} during this run. The results are given in full in appendix 3.4.	This system appears relatively clean at this site but shows some increase in $NH_4(N)$ during rainfall events.	Further investigation further upstream required

Key to Table: SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 5.3 Investigation into Water Quality in Hall Brook.

Date	Location	Results	Comments	Conclusions
6/12/99 to 12/12/99 run 5	St Paul's cemetery	After the first rain event on 6 December $NH_4^+(N)$ peaks of up to 1 mg l^{-1} were recorded which then settled back to an average of 0.1mg l^{-1}. DO levels fell following the storm on 10-11 December. The results are given in full in appendix 3.5.	There are still some signs of local organic contamination in this system	Possibly resulting from chemical or sewerage sources around the Dunlop site.
	Lythalls Lane Manhole 971	$NH_4^+(N)$ levels remained constant throughout the run as did Dissolved Oxygen saturation at around 88%. The results are given in full in appendix 3.5.	Slight peaks in $NH_4^+(N)$ recoded during rainfall events as reflected in conductivity and pH readings which both dropped during increased flows.	Less impact recorded on this side arm feeding to the culverted watercourse.
	Marshdale Avenue – Dunlop arm Manhole 113	Ammonium peaks are slightly higher than upstream but correspond to rainfall events. Otherwise stable results obtained for $NH_4^+(N)$ and also DO, which averaged around 65% saturation. The results are given in full in appendix 3.5.	These results denote some local input of organic matter to the system below Lythalls lane	Further investigation and the use of barbed wire traps required between Lythalls Lane and Marshdale Avenue on this arm of the culvert.
	Hen lane manhole 052	Fault with $NH_4^+(N)$ probe until second rainfall event. Ammonium after this time is negligible. Dissolved Oxygen levels remained stable at around 100% saturation The results are given in full in appendix 3.5.	**After the last run an investigation revealed a link between the parallel sections of foul and surface water sewers at Parkgate Road and a minor leak on the foul. This link was excavated and removed immediately and the leak fixed.**	Removal of the connection between foul and storm sewer and the repair of the minor leak at this point on the foul sewer has resulted in a great improvement in water quality This would not have been found without monitors.
	Marshdale arm – Parkgate arm Manhole 114	These results are unusual in that they show an increase in $NH_4^+(N)$ until there is a storm event The results are given in full in appendix 3.5.	Suspect that probe was out of the water causing 'drift' until rainfall event recovered sensor	Unreliable results.

Key to Table: SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 5.3 Investigations into Water Quality in Hall Brook.

Date	Location	Results	Comments	Conclusions
14/1/00 to 24/1/00 run 6	Lythalls Lane Manhole 973	Dissolved Oxygen probe failed or recorded an average of only 16% saturation after the second day of the run. $NH_4^+(N)$ peaks occurred daily with large increases to 12.0 mg l^{-1} in the last 2 days. Conductivity and pH spiked and fell again every 2 days just after midday The results are given in full in appendix 3.6.	Barbed wire traps installed at all sites in addition to monitors. Spikes in conductivity/pH results occur at the same time of day, every other day whilst $NH_4^+(N)$ peaks occur at breakfast time and early evening each day. **Only 1 short rainfall event in this run.**	Barbed wire traps clear but 'liquid' contamination suspected. Rhythmic nature of discharge indicates industrial process or practice. Ammonium contamination may be from a domestic source reflecting mealtimes.
	Allied Close manhole 082	Results recorded duplicated those found upstream at Lythalls Lane although Dissolved Oxygen saturation had improved and conductivity peaks were less marked The results are given in full in appendix 3.6.	As above	As above
	Stadium Close Gattic (heavy concrete) cover	Results recorded duplicated those found upstream at Lythalls Lane and Allied Close. Ammonium peaks were higher at over 8mg l^{-1} The results are given in full in appendix 3.6.	As above.	Higher Ammonium levels indicated some addition below Allied Close site indicating foul misconnection in Stadium Close itself. Further investigation required by Environmental Health
	Dunster Place Gattic (heavy concrete) cover	Results mirrored those found at sites above this point but all values were reduced with $NH_4^+(N)$ levels below 5 mg l^{-1} at all times. Dissolved Oxygen saturation was again reduced to an average of 50% The results are given in full in appendix 3.6.	As above	Further investigation of both suspected inputs required.

Key to Table: SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 5.3 Investigations into Water Quality in Hall Brook.

Date	Location	Results	Comments	Conclusions
11/2/00 to 21/2/00 run 7	Lythalls Lane manhole 971	$NH_4^+(N)$ peaks to 4.8 mg l^{-1} with rise following final rainfall event of 9.8 mg l^{-1}. Dissolved Oxygen level fairly constant at around 80-90% saturation. The results are given in full in appendix 3.7.	This site is located on a side arm taking Lythalls lane drainage to the culvert	Some minor rain related increases in $NH_4^+(N)$, which may point to local drainage with misconnections, which are flushed through or may be due to local flooded/ leaking sewerage systems contaminating storm sewer.
	Lythalls Lane manhole 974	Three peaks of non rain related conductivity as identified downstream but also a fourth on 11 February. The results are given in full in appendix 3.7.	Dissolved Oxygen levels erratic following first storm event and affected at each rise in flow. The monitor ceased working (either casing breached or out of flow) on 18 February.	Pollution appears to be above or near this point on the main culvert. Further investigation required above and below this point.
	Allied Close manhole 082	The pH showed an increase during the first storm event which then dipped slightly with subsequent events. Ammonium peaks corresponded more closely to rainfall events and the initial wet weather period took the readings off the scale The results are given in full in appendix 3.7.	$NH_4(N)$ peak precedes the rise detected at Stadium Close downstream	On this occasion the pollution was identified upstream of this site. It is possible that there is a second,(storm related) source above this point and a local source (non storm related) at Stadium Close
	Stadium Close	High $NH_4^+(N)$ levels recorded following first storm event for 3 days with minor peaks corresponding to other storms. The pH increases at each storm event The results are given in full in appendix 3.7.	Not all recorded ammonium detection coincides with wet weather events.	Local ammonium source suspected at or above this point.
	Dunster Place	Max. $NH_4^+(N)$ peak at 18.6 mg l^{-1} 17 February. Dissolved Oxygen remained at around 83% with only minor storm related drops. 3 of the conductivity peaks (14, 16 and 18 February) do not relate to storm events recorded at finham The results are given in full in appendix 3.7.	$NH_4^+(N)$ Peak not storm related Some of the conductivity peaks not storm related	Pollution source upstream of this point requires further investigation.

Key to Table: SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 5.3 Investigations into Water Quality in Hall Brook.

Date	Location	Results	Comments	Conclusions
10/3/00 to 20/3/00 run 8	St Paul's cemetery	4 large $NH_4^+(N)$ peaks (max11mg l^{-1}) recorded which do not relate to rainfall on 12, 13, 15 and 18 March.. Rainfall event (14 March) resulted in rise of 2 pH units. **Single rainfall event on 14 March.** The results are given in full in appendix 3.8.	This run was designed to investigate the culvert above Lythalls Lane which was indicated as the main source of contaminant prior to receiving rainfall data relating to the last run. D/S of Dunlop Ltd site.	Ammonium source may relate to industrial process above this point discharging to storm sewer. Large increase in pH value during rainfall event may also be trade effluent related.
	Holbrook Lane manhole 544	Non rainfall related ammonium peaks recorded with falling DO % saturation The results are given in full in appendix 3.8.	Manhole D/S of main interceptor Dangerous site because of heavy traffic.	Suspect ammonium source from Dunlop site and/or foul sewer on Holbrook lane. **Foul sewer inspected by Coventry CC. Suspect overflow pipe located and blocked off**
	Holbrook Lane manhole 534	Ammonium peak during rainfall event followed by smaller peaks also shown downstream at manhole 544. The results are given in full in appendix 3.8.	Side arm taking drainage from Dunlop frontage (no interceptor) Rainfall related ammonium peak following minimal activity	Suspect low flow in manhole prior to rainfall event. Organic pollution evident in surface water sewer not sampled since 1980s. Dunlop site suspected. Further investigation required. Monitors required elsewhere until May.

Key to Table: SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 5.3 Investigations into Water Quality in Hall Brook.

Date	Location	Results	Comments	Conclusions
12/05/00 to 22/5/00 run 9	St Paul's cemetery	Ammonium probe fault until storm event on 17 May. $NH_4^+(N)$ peaks (max> 8mg l^{-1}) reflect rainfall events on 17 may onward. Non rainfall related conductivity peaks also identified. The results are given in full in appendix 3.9.	This run was to confirm suspicions of trade effluent from Dunlop discharging to the storm sewer.	This point is downstream of a large bypass interceptor at Dunlop ltd and the first peak may show a first flush effect of an ammonium source from the site drainage.
	Holbrook Lane manhole 544	Daily $NH_4^+(N)$ peaks of up to 4.4 mg l^{-1} **prior to the rainfall event** Low and erratic results for D.O. falling to <40% saturation. The results are given in full in appendix 3.9.	This manhole is immediately above manhole 533 and closer to the Dunlop outlets	The results suggest an industrial process is involved which is discharging illegally to the storm sewerage system
	Holbrook Lane manhole 533	As above with peaks to a maximum of around 17mg l^{-1}. The pH rises as does conductivity with each discharge of contaminant. The results are given in full in appendix 3.9.	Monitor makes identification of intermittent TE discharge possible.	Strong evidence of industrial discharge from the site upstream of this point.
	Holbrook Lane Manhole 534	Ammonium peaks showed daily peaks to a maximum of over 17.2mg l^{-1}. Following the second rainfall event the peaks subsided. DO saturation levels reduced with each rainfall event. The results are given in full in appendix 3.9.	Side arm taking drainage from Dunlop frontage (no interceptor) and Southern side of site only.	Conductivity and pH probes likely to be out of flow until rainfall event. $NH_4(N)$ contamination from daily source on Southern side of site requires investigation.
	Foleshill park upstream of Dunlop interceptor (main culvert) (monitoring point 22, figure 4.9)	Numerous regular peaks of $NH_4^+(N)$ during dry weather period to 2.4 mg l^{-1} The results are given in full in appendix 3.9.	Consistent impact on surface water sewer of regular low-level ammonium source.	$NH_4(N)$ results denote regular trade effluent discharge to surface water sewer from North-West side of site
	Foleshill park downstream of Dunlop interceptor (monitoring point 21, figure 4.9)	Ammonium levels high and erratic during dry weather period which fall to a constant level after the first rainfall event. The results are given in appendix 3.9	Results suspect	Further investigation required.

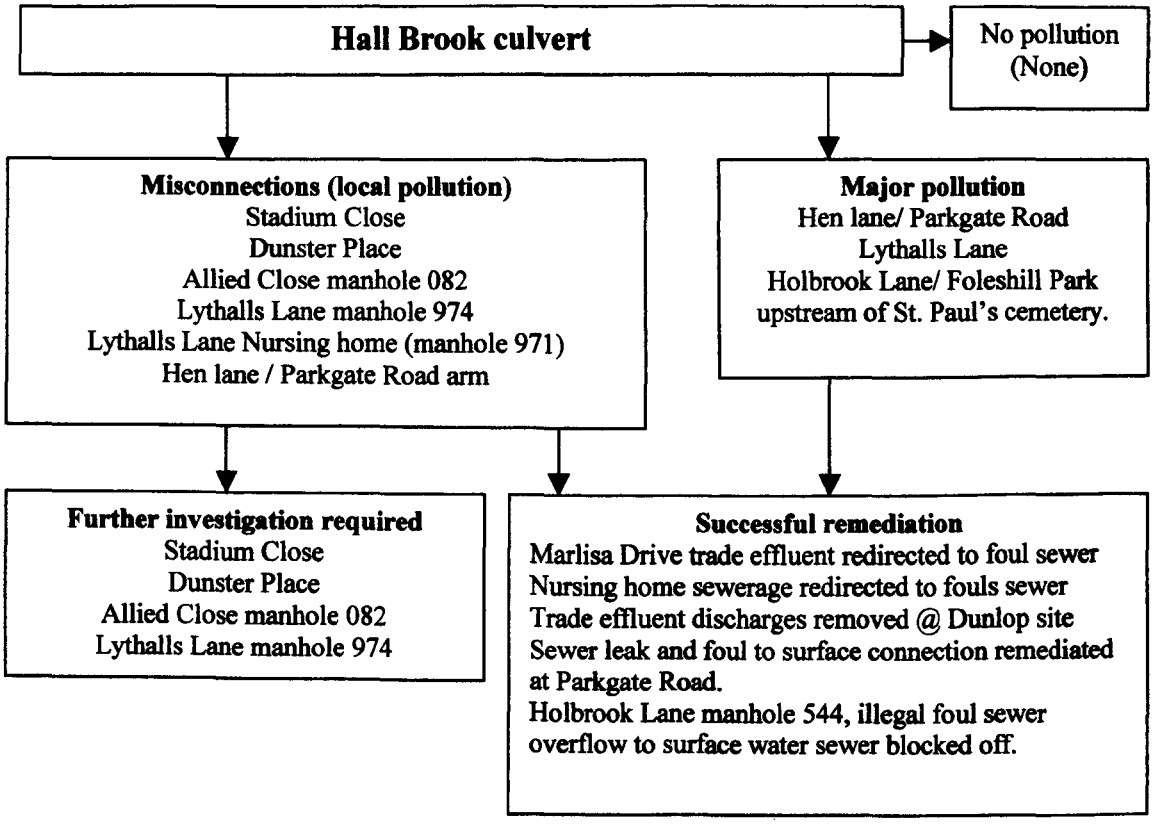
Key to Table: SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 5.3 Investigations into Water Quality in Hall Brook.

Date	Location	Results	Comments	Conclusions
2/6/00 to 19/6/00 run 10	Foleshill park upstream of Dunlop interceptor (monitoring point 22, figure 4.9)	Conductivity results show regular peaks and Ammonium increases in dry weather before dilution by rainfall events with a maximum of 18mg l^{-1} on 6 June. Dips in DO reflected each storm event. The results are given in appendix 3.10.	High levels of ammonium recorded	The source of contamination from the Northwest side of the site requires urgent investigation on site.
	Foleshill park downstream of Dunlop interceptor (monitoring point 21, figure 4.9)	The results are more stable downstream of the large interceptor on site but still demonstrate fluctuations in the order of one pH unit during each rainfall event. Minor peaks in ammonium and conductivity were demonstrated The results are given in appendix 3.10.	Occasionally interceptor is blocked off for maintenance and is not available to balance flow.	Possibly other contaminated sources entering large underground interceptor direct but interceptor acts as balancing tank for intermittent discharges in dry weather.
29/6/00 to 9/7/00 run 11	Dunlop site drainage Downstream of interceptor (monitoring point 21, figure 4.9)	Dunlop site drainage shows storm related discharges with minor ammonium peaks but also some non-rainfall related peaks to 6.2mg l^{-1}. The results are given in appendix 3.10.	Use of monitor allowed intermittent discharges relating to trade processes to be removed. Discussion with Company, internal drainage study and report required on activities within the site	**Commercially confidential report identified trade effluent sources to be removed.**
	Holbrook Lane manhole 534 downstream of Dunlop South (no interceptor)	Major $NH_4^+(N)$ peaks identified to maximum of 40mg l^{-1}. The pH fluctuated over 2.5 pH units from 8.o to 6.5 during the initial wet weather period. The results are given in appendix 3.10.	Use of monitor allowed intermittent discharges relating to trade processes to be removed. Discussion with Company, internal drainage study and report required on activities within the site	**Commercially confidential report identified trade effluent and misconnected drainage sources to be removed urgently.**

Key to Table: SC – Specific Conductivity, DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

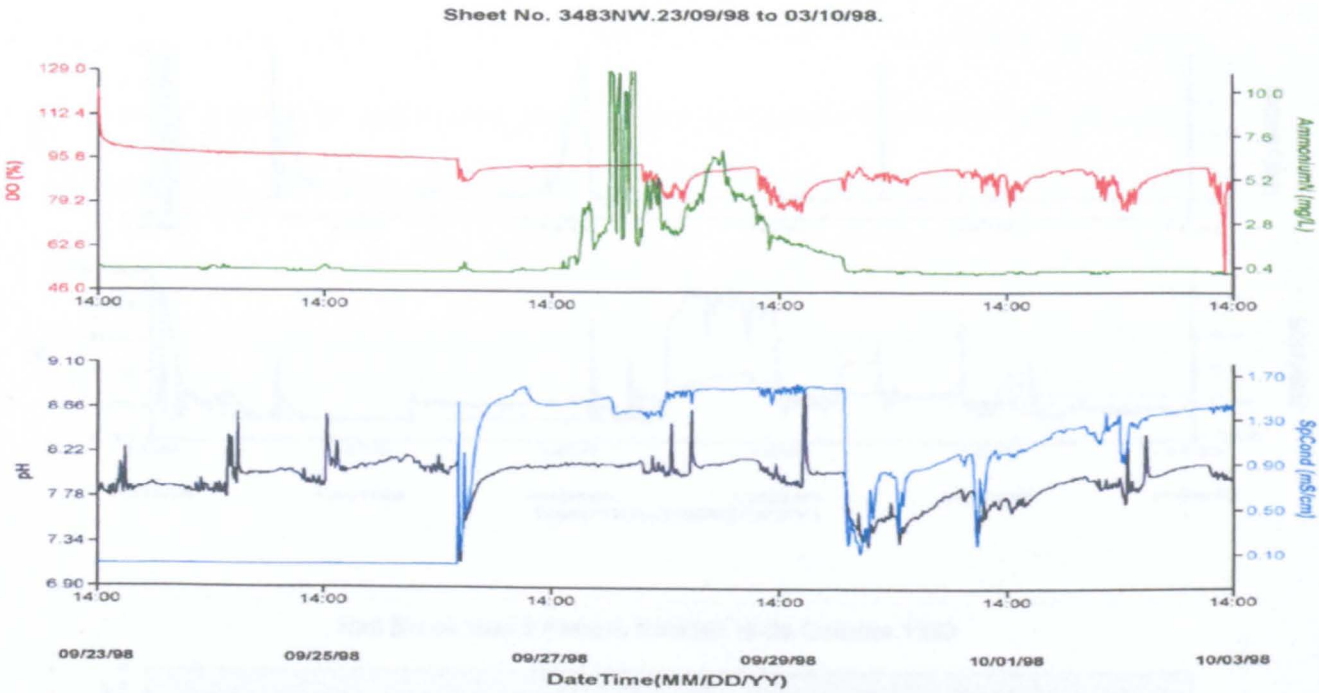
Figure 5.9 Methodology and summary of results - Hall Brook culvert

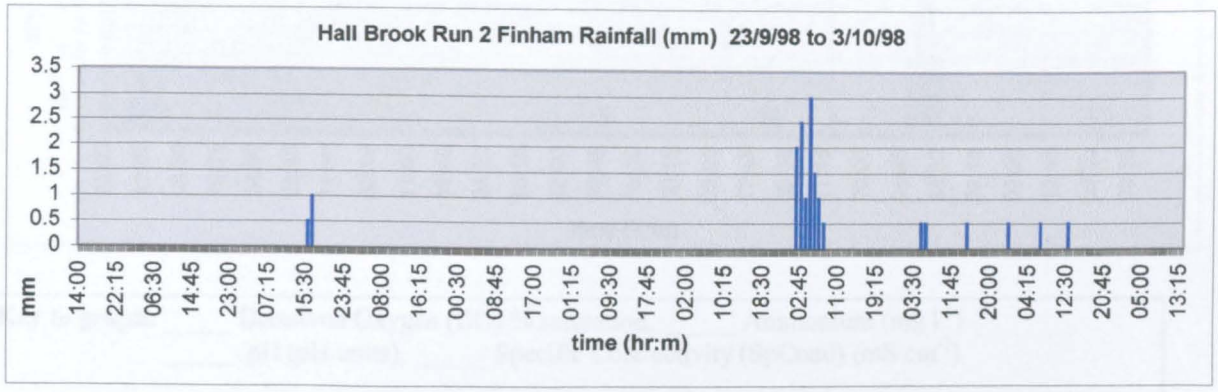


The use of continuous monitors during run 2 confirmed that the Hen Lane area was contaminated, and the daily ammonium and pH peaks suggested a direct misconnection rather than as a result of a storm related overflow, as shown in Figure 5.10.

Ammonium levels on the 26 September exceeded the project benchmark (1.3 mg l^{-1}) by a factor of 10 during dry weather as shown in Appendix 3.2 and table 5.3. There were low Dissolved Oxygen concentrations, coupled with periodic high ammonium values, at the monitoring point in Lythalls Lane during run 3 between 16 and 26 October 1998 (Figure 5.11). A large storm event occurred on 21 October at 13:15 hours, and continued until 13:15 hours the next day, which gave a slight increase in pH, SC and Dissolved Oxygen.

Figure 5.10 Continuous monitor results for Hen Lane manhole 052 and Finham rainfall, 23 September to 3 October 1998

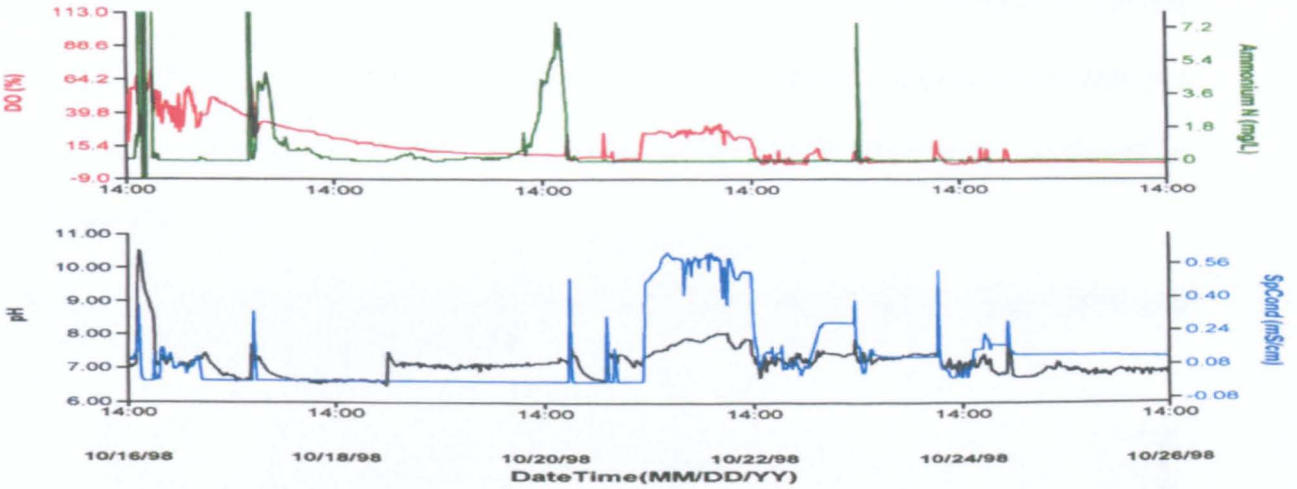


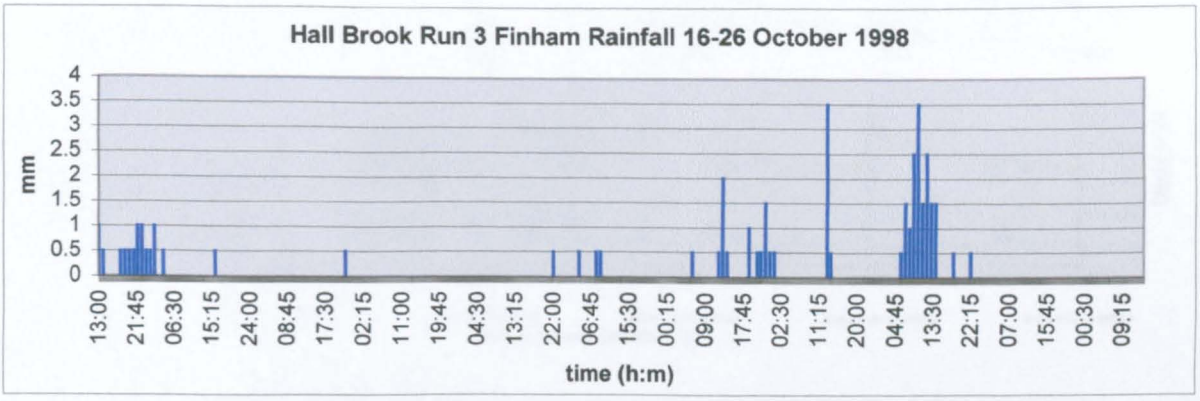


Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

At 19:00 hours on 16 October, a peak of 16.9 mg l^{-1} ammonium occurred (in conjunction with a storm event), with a final peak of 7.40 mg l^{-1} ammonium during a later event with a higher flow. Dissolved Oxygen levels dropped from around 60% to around 15% saturation, rising to 25% during the storm event, but immediately falling down to 2.7%, as shown in Figure 5.11.

Figure 5.11 Continuous monitor results for Lythalls Lane manhole 971 and Finham rainfall, 16-26 October 1998.



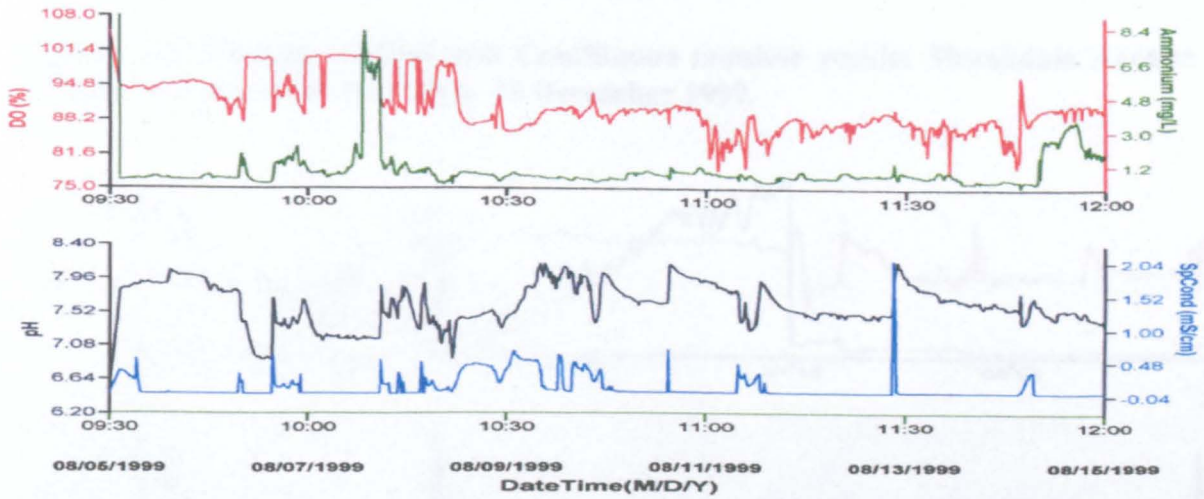


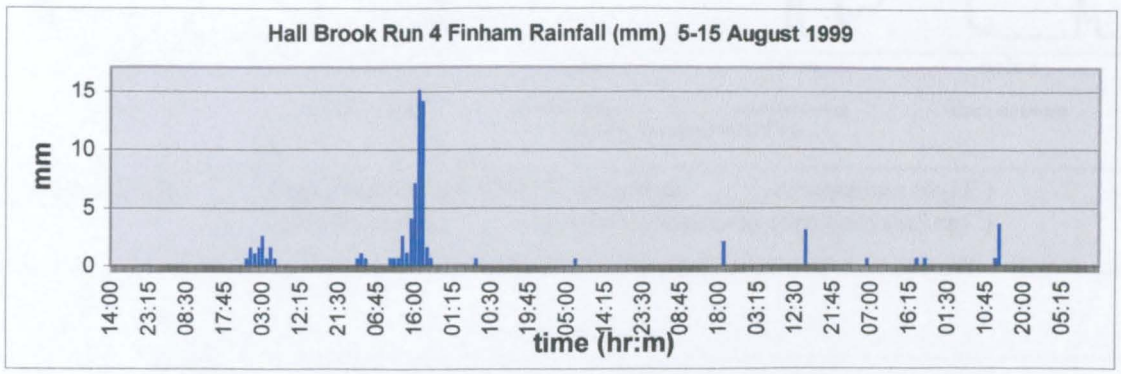
Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

The Dissolved Oxygen saturation values were very low for what was originally thought to be a clean arm of the culverted watercourse, though when it was removed after the monitoring period, the probes were covered in foul sewer debris. Further monitoring of the storm water system highlighted a 20-metre length of the brook where foul sewage was entering the system. Using CCTV, a misconnection from the foul sewer of a 40-bed residential care home was identified. The home had been extended 5 years previously, and the builders had connected the foul water sewer directly into the storm water sewer. All sewerage from the property was redirected to the foul sewer in March 1999.

Continuous monitors recorded high levels of ammonium on the Dunlop arm of the Hall brook culvert (Figure 4.9), which indicated both storm and dry weather contamination sources. A potential trade effluent was identified at Marlissa Drive during run 4 (table 5.3), by detection of an ammonium peak which was not directly storm event related, but may have been indicative of a flush through of collected contaminants, as shown in Figure 5.12

Figure 5.12 **Continuous monitoring Marlissa Drive, Run 4, 5-15 August 1999 and associated (Finham) rainfall figures**

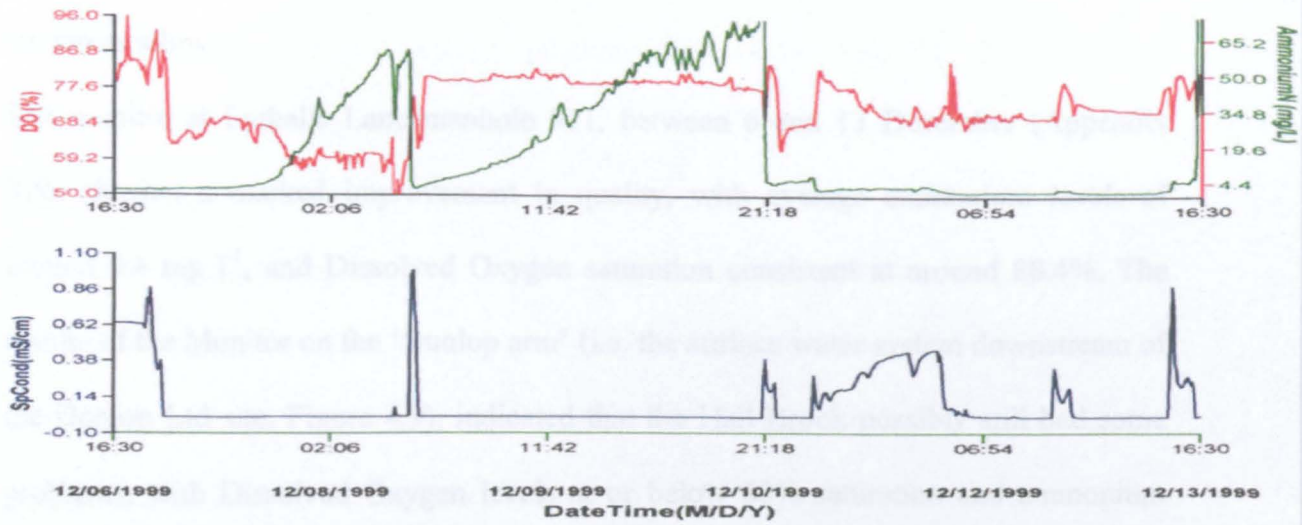




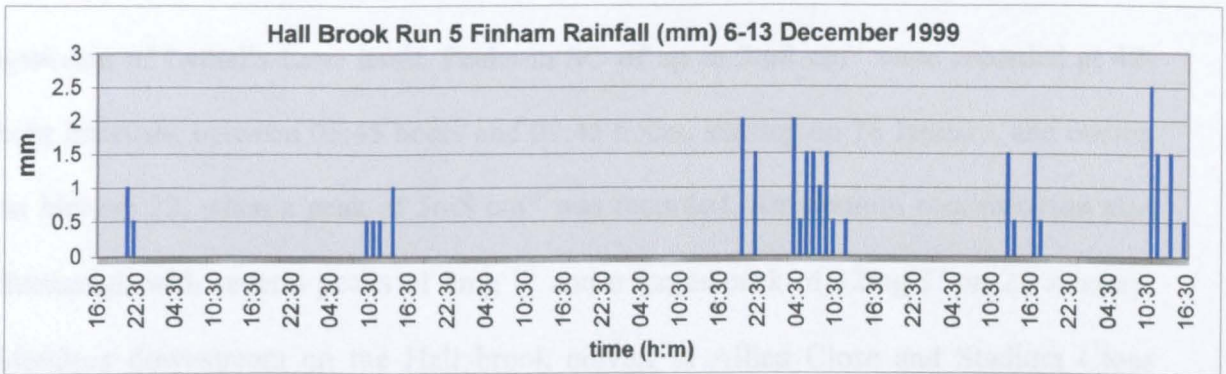
Key to graph: ____ Dissolved Oxygen (DO) % saturation, ____ Ammonium (mg l^{-1})
____ pH (pH units), ____ Specific Conductivity (SpCond) (mS cm^{-1})

This was later identified as the result of trade effluent, involving wash down liquors from a small pet food company on the industrial estate. The high levels of ammonium and low levels of Dissolved Oxygen saturation detected at Lythalls Lane during run 3 were much improved in run 4, following the detection of a major misconnection from the large nursing home on Lythalls Lane. The monitor on the Parkgate arm of Marshdale Avenue at manhole number 114 (Figure 4.9) showed a fall in Dissolved Oxygen levels below 52% saturation on 6 December following a storm event, and the ammonium levels rose to nearly 60mg l^{-1}, as shown in Figure 5.13.

Figure 5.13 Finham rainfall and Continuous monitor results Marshdale Avenue (Parkgate Arm, manhole 114) 6- 13 December 1999.



Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})



Between 9 and 10 December the ammonium value peaked at over 65 mg l^{-1} $NH_4^+(N)$, indicating gross contamination of this arm. Following this investigation, a survey found foul debris further upstream in the surface water sewerage system, and the source was traced to a point between two manholes on Parkgate Road. A straight cross-connection between the foul and surface system was discovered, which was subsequently excavated and removed. The 1963 sewer replacement map (Coventry City Council, 1963) (Section 3.12) also indicates the possibility of a storm overflow, numbered O4, which was not identified for removal during the construction of the Sherbourne Valley sewer in 1963-1969. This overflow still requires investigation by Severn Trent Water Ltd., and further monitoring by the Environment Agency using continuous water quality monitors, when resources allow.

The monitor at Lythalls Lane manhole 971, between 6 and 13 December (Appendix 3.5), showed a marked improvement in quality, with average ammonium levels of around 0.4 mg l^{-1}, and Dissolved Oxygen saturation consistent at around 88.4%. The results of the Monitor on the 'Dunlop arm' (i.e. the surface water system downstream of the Dunlop Ltd site, Figure 4.9), indicated that the Hall Brook possibly still had some problems; with Dissolved Oxygen levels at or below 60% saturation and ammonium peaks to nearly 2mg l^{-1} (Appendix 3.5). For the run between 14 and 24 January 2000 (run 6, Figures 5.14-5.18), a monitor was placed in the main river culvert on Lythalls Lane at manhole 973, to determine the extent of contamination arising from the areas upstream of Lythalls Lane itself. Peaks in SC of up to 3mS cm^{-1} were recorded at 48-hour intervals, between 06:45 hours and 09:45 hours, starting on 16 January, and ending on January 22, when a peak of 5mS cm^{-1} was recorded. Ammonium concentration also fluctuated, with several peaks of 3mg l^{-1} and a larger peak of 12mg l^{-1} on 22 January. Monitors downstream on the Hall brook culvert at Allied Close and Stadium Close

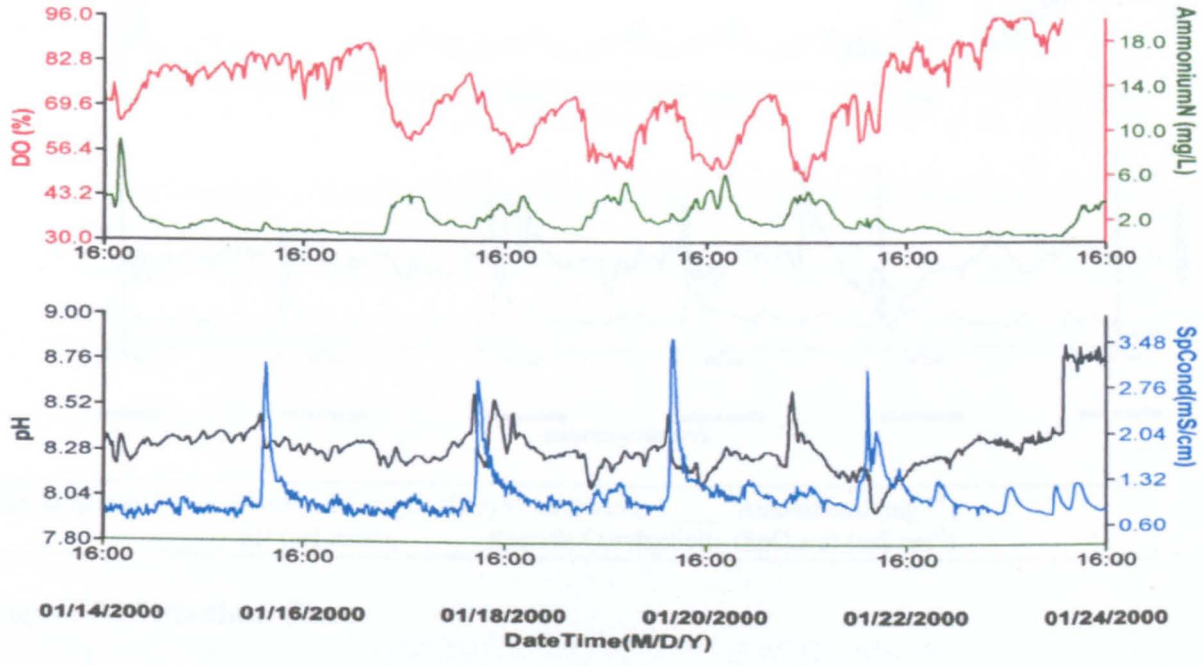
(monitoring points numbered 12 and 11 respectively, Figure 4.9) mirrored the Lythalls Lane (manhole 973) results (Figures, 5.14 and 5.17 below).

The Dunster Place monitor results (monitoring point 9, Figure 4.9) were similar to those of the upstream monitors. A barbed wire trap at this point had collected a large quantity of sewer rag, which possibly indicated domestic sewage misconnections in the local area or an unknown foul sewer overflow operating intermittently, upstream. Regularly repeating peaks in SC and pH were also recorded at manhole 973 on Lythalls Lane and all of the other sites monitored during run 6, with little correlation to the single rainfall event during the monitoring period (Figures 5.14-5.18). Dissolved Oxygen levels dipped as ammonium levels increased during this period of monitoring.

This contamination, during a period of relatively little rainfall, indicated a further source of sewage misconnection, or trade effluent, above the Lythalls Lane monitoring point at manhole 973, and further investigation revealed a storm relief connection on Holbrook Lane, as a 9 inch overflow to a 9 inch surface water sewer (Coventry City Council, 1963). The overflow was not removed as planned in 1963 (Section 3.12), but was sealed off with concrete to prevent further overflow of foul sewage, as a result of this monitoring data. The results for run 6 on the Hall Brook system are given in Figures 5.14 to 5.18.

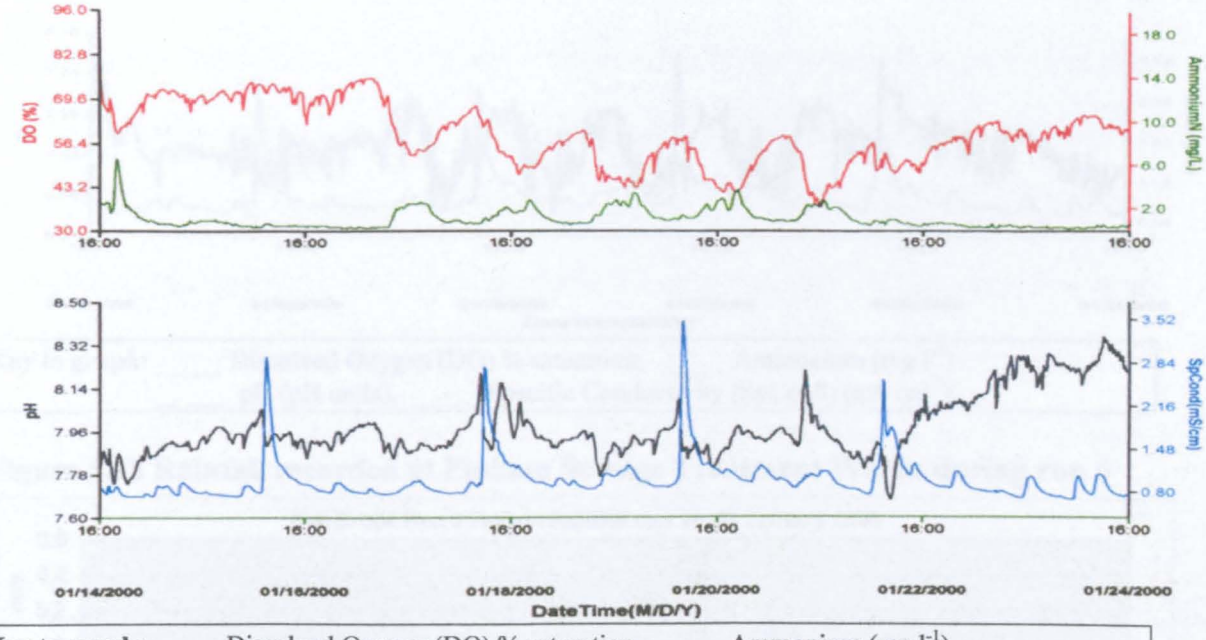
Figures 5.14 – 5.18 Continuous monitoring results for run 6 on the Hall Brook culvert 14-24 January 2000 with associated rainfall (Finham) for the period.

Figure 5.14 Allied Close



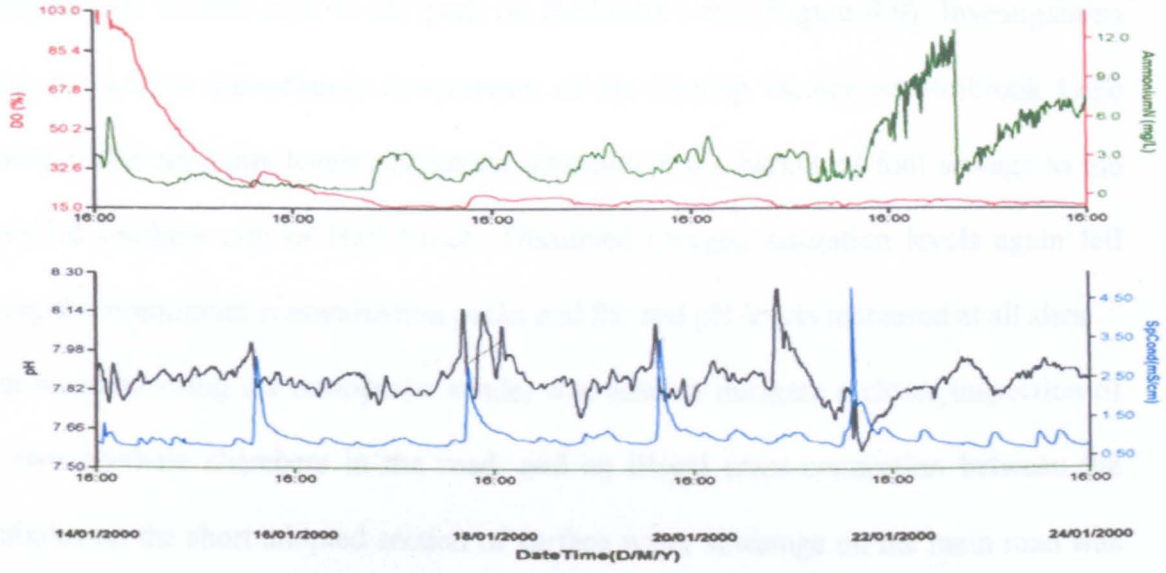
Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

Figure 5.15 Dunster Place



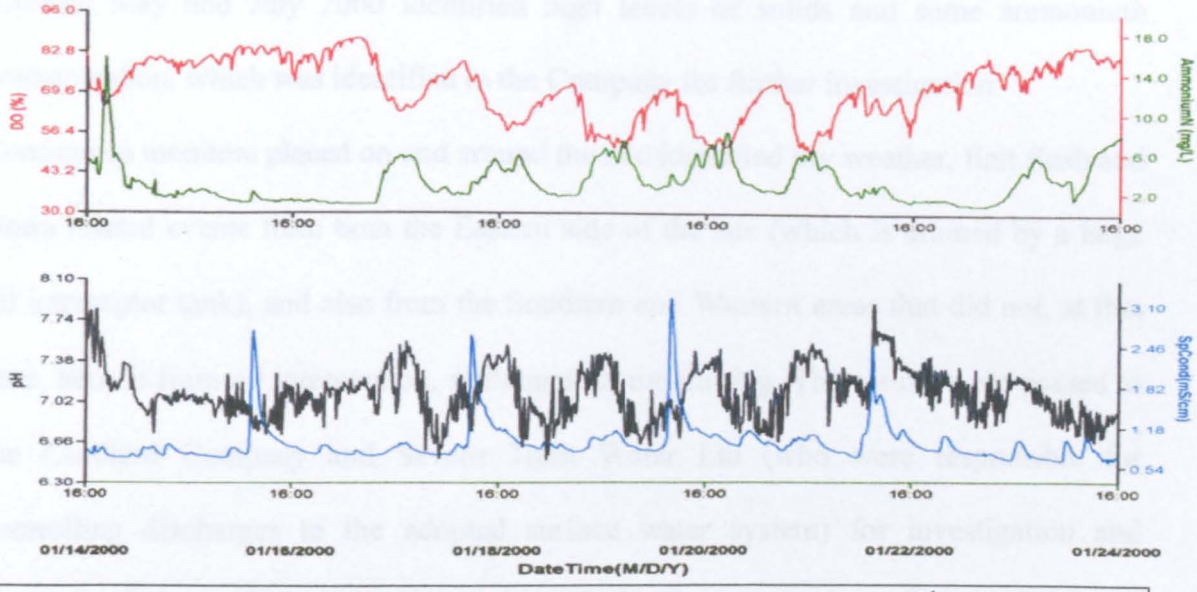
Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

Figure 5.16 Lythalls Lane



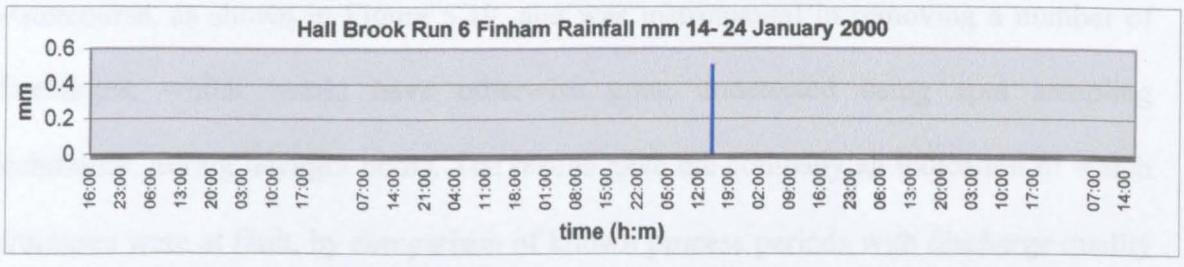
Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

Figure 5.17 Stadium Close



Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

Figure 5.18 Rainfall recorded at Finham Sewage Treatment Works during run 6



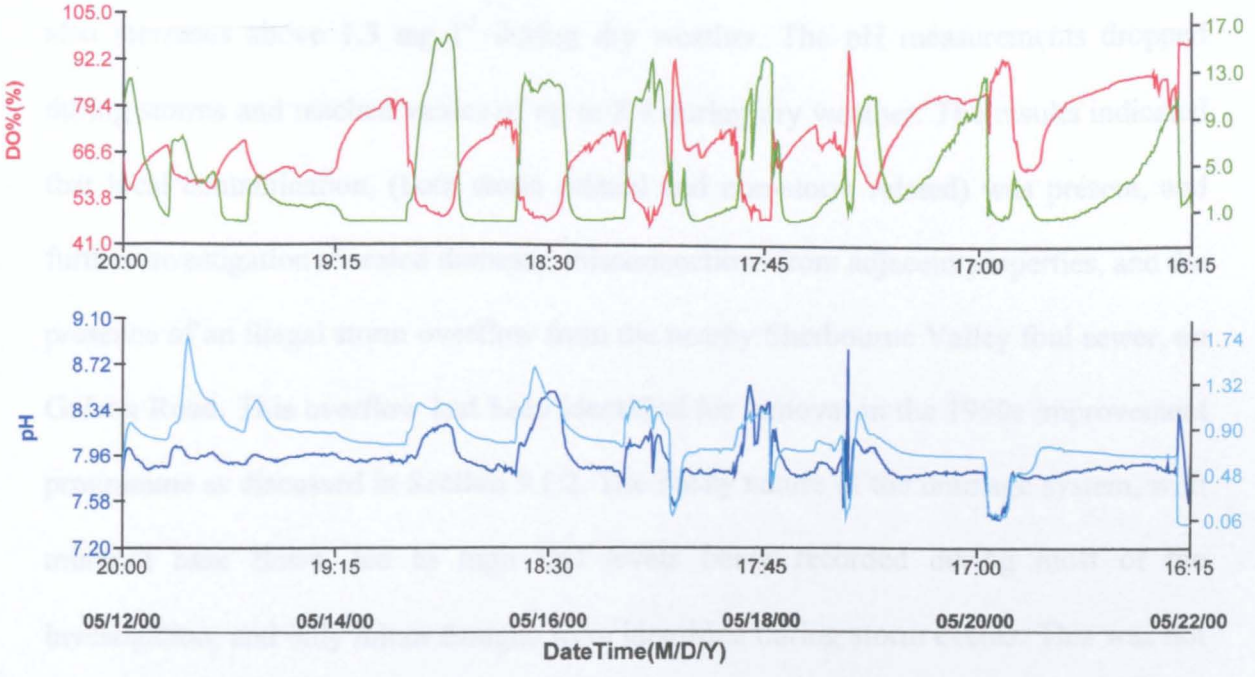
The final investigations on this system (runs 9-11, table 5.3), concentrated on an industrial site located next to the park on Holbrook Lane (Figure 4.9). Investigations using the sondes immediately downstream of the Dunlop factory on Holbrook Lane revealed high ammonia levels, indicating intermittent discharges of foul sewage to the culverted southern arm of Hall Brook. Dissolved Oxygen saturation levels again fell during the ammonium contamination peaks and SC and pH levels increased at all sites.

Data recorded using the multiprobe sonde, was used to instigate a closer inspection of the two manhole chambers in the road, and an illegal cross-connection between the manholes on the short adopted section of surface water sewerage on the main road was identified, as discussed previously. The Water Company and Coventry City Council blocked this connection pipe off in the following couple of months. Subsequent surveys between May and July 2000 identified high levels of solids and some ammonium contamination, which was identified to the Company for further investigation.

Continuous monitors placed on and around the site identified dry weather, first flush and storm related events from both the Eastern side of the site (which is drained by a large oil interceptor tank), and also from the Southern and Western areas that did not, at that time, benefit from oil interception, settlement or monitoring. The results were passed to the Landlord Company and Severn Trent Water Ltd (who were responsible for controlling discharges to the adopted surface water system) for investigation and removal of the polluting discharges identified. The monitoring of these industrial discharges was very successful in showing intermittent contamination in the culverted watercourse, as shown in Figure 5.19, and was instrumental in removing a number of discharges, which would have otherwise gone undetected using spot sampling techniques, during daylight hours. The results gave the company an indication of which processes were at fault, by comparison of known process periods with discharge quality

results and the contaminant peaks identified, as demonstrated in Figure 5.19. The evidence was not disputed, and number of illegal discharges involving machine cutting oils (suds oil), sink misconnections and process effluents were removed. Other sites monitored gave consistent results and are given in Appendix 3.

Figure 5.19 Ammonium peaks identified at Holbrook Lane manhole number 533 (downstream of the Holbrook Lane industrial site) during dry weather



Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})
_____ pH (pH units), _____ Specific Conductivity (SpCond) (mS cm^{-1})

5.2 Conclusions- Phase 1

5.2.1 Swan Lane Culvert and Gulson Road Surface Water Sewer

The investigation into the Swan Lane culvert and Gulson Road surface water drainage system was hampered by heavy traffic conditions along the run of the sewer, which made the deployment of the continuous monitors more hazardous. The average results

for ammonium at the Northern end of Gulson Road (table 5.1) were around 2.5 mg l^{-1} during dry weather, peaking to more than four times the concentration of 1.3 mg l^{-1} identified as a 90-percentile for a class C (fairly good) watercourse (Section 2.4.2). The results therefore indicate a level of organic contamination at this point, but the position of the surface water sewer (along a busy main road), requires that further investigation upstream of this point would involve the use of an equipped team of operatives with full Health & Safety assessments and procedures. The drainage system downstream of this point demonstrated ammonium peaks linked to rainfall levels, as before, but there were also increases above 1.3 mg l^{-1} during dry weather. The pH measurements dropped during storms and reached values of up to 8.4 during dry weather. The results indicated that local contamination, (both storm related and non-storm related) was present, and further investigation revealed domestic misconnections from adjacent properties, and the presence of an illegal storm overflow from the nearby Sherbourne Valley foul sewer, on Gulson Road. This overflow had been identified for removal in the 1960s improvement programme as discussed in Section 3.1.2. The flashy nature of the drainage system, with minimal base flows, led to high DO levels being recorded during most of the investigation, and only minor troughs were identified during storm events. This was not the case in the Swan lane Culvert, where the base flow, derived from groundwater, canal overflows and possible misconnections, gave better coverage of the continuous monitor probe to give more consistent and representative measurements. In general, where culvert flows were sufficient to cover the probes, the continuous monitors gave a good representation of the relative impacts of contaminants on specific stretches of the Swan Lane culvert, and Gulson Road surface water sewers. The data identified a number of major continuous or intermittent pollution sources, which would not have previously been traceable by spot sampling, with the limited resource available to this work.

5.2.2 Springfield Brook

The Springfield Brook survey was more complex to undertake, involving access through large concrete covers to deep chambers and the shallow broad culvert. The complexity of the drainage system and urban nature of the catchment, meant that the more serious problem areas probably overshadowed a number of minor pollutant sources. The presence of a large weir overflow from the Coventry Canal to the drainage system appeared to impact on the results, adding dilution to the culvert flow and smoothing the peaks and troughs identified during the monitoring period. The canal is a class C (fairly good) watercourse, receiving no trade effluents or discharge from major drainage systems in the area, and any effect on quality is likely to be one of dilution.

Low flows, and periods of no flow at all in the upper reaches of the drainage system in the mainly residential area of Keresley Heath (see Figure 4.8, monitoring points 1-6) led to generally high levels of DO saturation being recorded, and ammonium peaks recorded during and between storms suggested local residential misconnections and first flush concentrations in the shallow drainage systems. The monitor results correctly identified the unusual levels of the pollutants in the foul sewer, which had been mistakenly monitored at Dickens Road during run 6. The ammonium peaks and ammonium troughs were erratic yet constant throughout the monitoring period, though interestingly the increase in DO saturation following rainfall events suggested a component of combined sewerage or groundwater infiltration, which is not uncommon in the older areas of Coventry. The results for this site give an indication of what can be expected in a residential foul sewer, and offer a useful comparison against both clean rainwater systems and surface water drainage systems contaminated with sewage from domestic misconnections, seepage from adjacent blocked foul sewers and illegal combined sewer overflows. Run 6 (table 5.2) also identified that although continuous

monitoring of surface water drainage systems with minimal base flows can be difficult, some indication of problem stretches can still be achieved. Where readings are falsely high or low throughout the monitoring period, specific events or discharges can still give rise to relatively significant peaks and troughs that can indicate the presence of a contaminated source. Point source pollution can then be confirmed by using targeted camera surveys or dye tracing techniques.

At and around the Courtaulds site the concentrations of Ammonium increased, and it was suspected that an organic source was impacting on the monitoring site. Ammonium levels at over 20 times the trigger level for this investigation (1.3 mg l^{-1}), suggested that an immediate survey of the drainage system, using CCTV, above this point was required. It was subsequently determined by targeted investigation, that an illegal trade effluent of high BOD and low volume, was located discharging into one of the surface water systems draining to the site on the Foleshill Road (see Figure 4.8).

Continuous monitoring at Springfield Place identified high levels of ammonium, and a large number of peaks and troughs for ammonium and DO saturation respectively. Similar results identified previously at other sites identified that this site was also likely to be a foul sewer. Further investigation of detailed sewer plans confirmed that this was the case, and the sampling point was moved to an adjacent chamber on the culverted watercourse at the same site. Although high ammonium levels at the new monitoring point indicated that the illegal trade effluent discharge had resumed, the results were more representative of a contaminated surface water sewer system, showing peaks of less than 14mg l^{-1}. At Cash's Lane the results also indicated that the illegal discharge had resumed. Further investigation at the point of discharge confirmed that this was the case.

5.2.3 Hall Brook Culvert

The use of continuous monitoring on the Hall brook culvert was very successful, and led to the removal of a number of sewage misconnections, several storm relief connections and a large number of illegal trade effluent discharges. Many of the discharges would have remained undetected if spot sampling of the upstream and downstream open sections had been used in isolation. The major continuous discharges again masked the minor pollution inputs, but as each source was identified and removed, it was possible to concentrate on a specific area of drainage to identify the more elusive intermittent or rain related discharges. Some equipment failures, low flows and storm damage hindered the possibility of obtaining accurate quantitative information in one investigative run, but again comparative results could be used when the levels of contaminant recorded were suspect. The correlation between specific determinands and between data from monitors placed in separate locations during the same investigation, was often good, and gave enough confidence in the results to progress the investigation to other areas, and make sound operational decisions relating to allocation of resources for intrusive investigations of the drainage system.

5.2.4 Summary.

The use of continuous monitors was very successful in tracing intermittent and illegal discharges in surface water drainage systems, and led to the removal of a significant number of illegal foul sewer overflows, industrial and commercial discharges, and misconnections from domestic foul sewer systems.

The investigation work was supported by the Severn Trent Water Ltd. as part of an effort to improve the water quality of storm flows arising from the City of Coventry, which could not be investigated as part of the Urban Pollution Management study (FR/CL 0002. FWR, 1994; Clifforde and Williams, 1998) previously funded by the Company and the

Environment Agency. It was hoped that any improvements made would complement the improvements to Finham Sewage Treatment Works, and result in a vastly improved situation following summer storms in the River Avon at Saxon Mill near Warwick, as detailed in Sections 3.6 –3.9. Whilst not entirely due to the improvements bought about by this investigation into urban runoff in the River Sowe catchment, nor from the improvements made following the UPM project, there has been a marked improvement in the water quality of the River Sowe (table 3.1 and Figures 3.4, 3.5 and 3.6) and River Avon catchments, as shown in table 3.2, and Figures 3.9 a)-e). This investigation work was not directly funded, and the technology employed was supported by other water quality work across the area. The water quality problems encountered were quickly addressed by approaching the problems identified to Severn Trent Water Ltd. and their Agents, in a spirit of co-operation and collaboration, rather than enforcement. On occasion, particularly where privately owned drainage systems were involved, the ability to use enforcement under the Water Resources Act 1991, was a necessity. The results obtained, and the success of the investigations using continuous monitors on culverted watercourses and surface water systems in urban areas confirms the hypotheses (Section 1.4) that:

... the use of continuous monitors can give an accurate graphical representation of the changeable nature of quality and flows in urban watercourses and assist in the investigation and removal of polluting intermittent organic discharges in a cost effective manner.

And furthermore that:

.... analysis of water quality during storm events at multiple sites on a continuous basis will reveal hitherto unknown cross connections between surface and foul sewers, broken sewers and industrial and commercial effluents quickly, and that removal of these

illegal discharges will result in a marked improvement in water quality, as identified by routine sampling programmes, for affected watercourses.

The success of this application of continuous monitors is discussed in relation to the objectives of this research in Chapter 8.

Chapter 6 will investigate the results obtained from using continuous monitors to identify intermittent sources discharging to the larger River Sherbourne culvert, in Coventry city centre, during storm events and dry weather. The impacts of a series of Combined Sewer overflows (CSOs) located upstream of the city centre culvert, and the culverted watercourses studied in Phase 1 (Figure 4.5) are determined (Section 6.1) and discussed (Section 6.2) in accordance with the methodology outlined in tables 4.6 and 4.7, and Figure 4.1. The results for Phase 2 were used as a baseline for pollutant concentrations, and as a comparison to determine any improvements in water quality during Phase 3. The later investigations (October 1999- September 2000) in Phase 2 (table 6.2), and investigations in Phase 3 (Section 7.1) also identified pollutants that cannot be measured using continuous monitors, such as heavy metals, SS and ortho-P, using automated sampling equipment (on some investigative runs as identified in table 4.7), in combination with the monitors during storm events and short periods of dry weather.

The final phase of the research (Phase 3) investigated the River Sherbourne following remediation of the CSO problem identified above (Figure 3.8), and the results are discussed in Chapter 7.

Chapter 6 Phase 2 Results

Introduction

Phase 2 of this research examined early data (1996 to 1997) obtained from monitoring the River Sherbourne at sites upstream and downstream of the culverted city centre section, as identified in Figure 4.10, and summarised in Tables 4.6 (methodology) and 6.1 (results). Further data, using continuous monitors upstream and downstream of the city centre from October 1999 to September 2000, was also obtained during Phase 2, to identify the impact of wet weather events prior to the replacement of six unsatisfactory combined sewer overflows with a new foul sewer and one high level storm relief overflow, as detailed in Section 3.5, Figure 4.10 and Tables 4.7 (methodology) and 6.2 (results). The research met the requirements of objectives 1.2 and 3, as detailed in Section 1.4, and discussed further in Chapter 8.

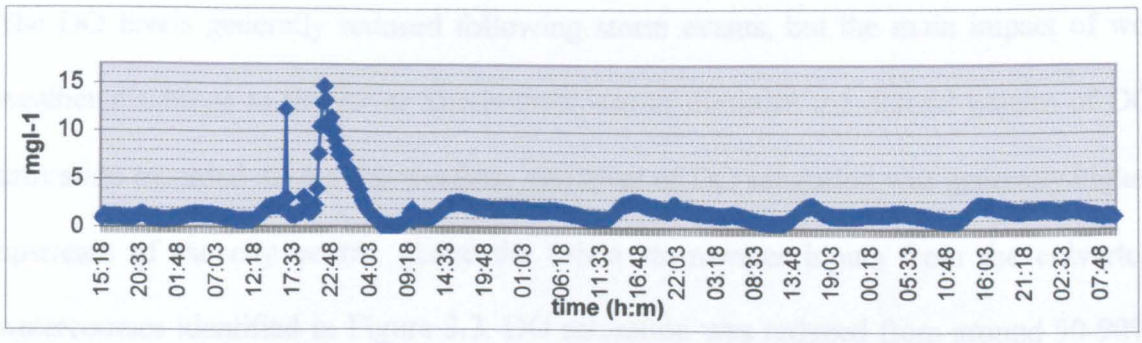
6.1 The River Sherbourne and Albany Road storm overflows

6.1.1 Early investigations results

A number of monitoring runs were carried out using YSI quality monitors, placed above and below the permitted combined sewer overflow outfall at Hope Street (Figure 4.10), situated immediately before the River Sherbourne enters the culvert passing under the City Centre (Figure 4.10). Monitors were also placed at locations in the open watercourse as the river emerges from the culvert, as identified in Section 4.4.1 and Table 4.6. The results are given in Appendix 4, and summarised in Table 6.1 (page 220). Initial investigations into the water quality of the River Sherbourne showed low Dissolved Oxygen levels and elevated ammonia levels at Waveley Road, upstream of the Hope Street outlet, and also at Rudge Road below the Combined sewer outfall, as shown in Appendix 4. The pumping station overflow, situated at Park Road upstream of the City, and consented discharges (now removed to foul sewer) from eight private

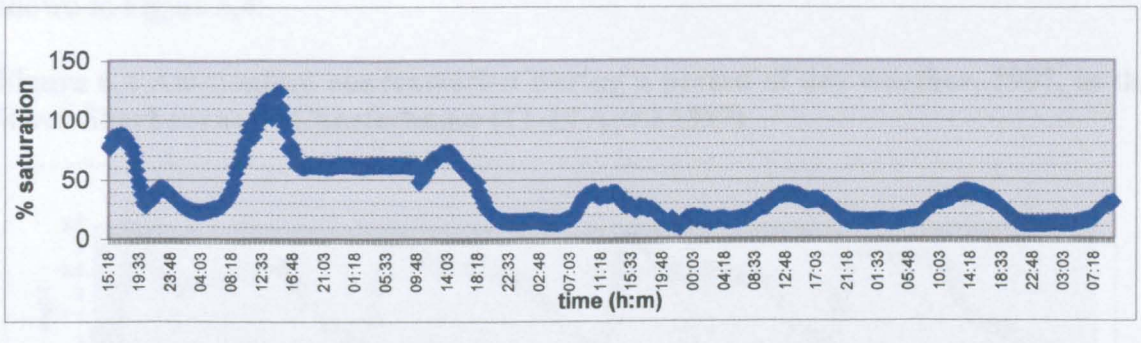
sewage treatment plants (including 3 hotels, 3 industrial estates, a large garage and a residential home), to Pickford Brook (Figure 3.2), were thought to be contributory factors. A continuous monitoring run between 2 - 8 April 1997 recorded a minor rainfall event, which was linked to an elevated peak of ammonia (15mg l^{-1}) in the watercourse at Charterhouse, as shown in Figure 6.1.

Figure 6.1 Ammonium concentration during the 1997 rainfall event in the River Sherbourne at Charterhouse (2-8 April 1997)



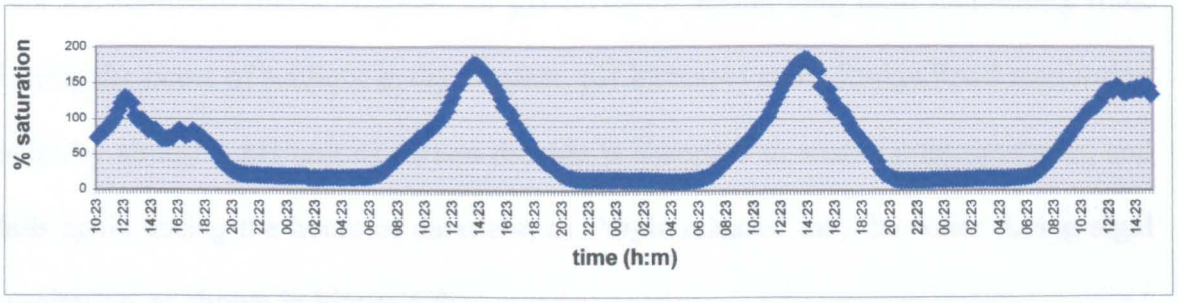
The continuous monitor showed the impact that the storm overflows and the culverted watercourses were having on the River Sherbourne at the Charterhouse GQA sampling point, with Dissolved Oxygen falling consistently to around 12% saturation, although diurnal variation was maintained, even at the reduced levels, as shown in Figure 6.2:

Figure 6.2 Dissolved Oxygen concentration during a 1997 rainfall event in the River Sherbourne at Charterhouse (2-8 April 1997)



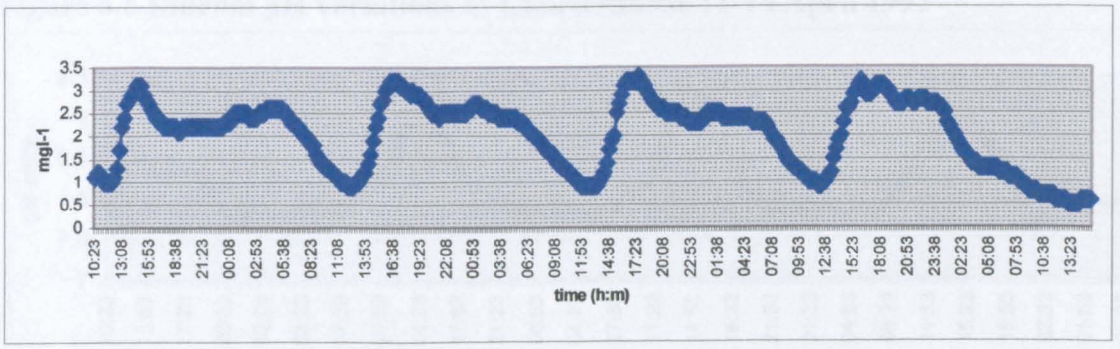
During a dry period at the same monitoring point, between 11 – 14 April 1997, the DO and ammonia readings still show a poor quality watercourse, which fails quality standards for ammonium and Dissolved Oxygen, but with more consistent results and a greater natural diurnal variation in oxygen saturation, as shown in Figure 6.3.

Figure 6.3 Dissolved Oxygen concentration during a period of dry weather, 1997, in the River Sherbourne at Charterhouse (11-14 April 1997)



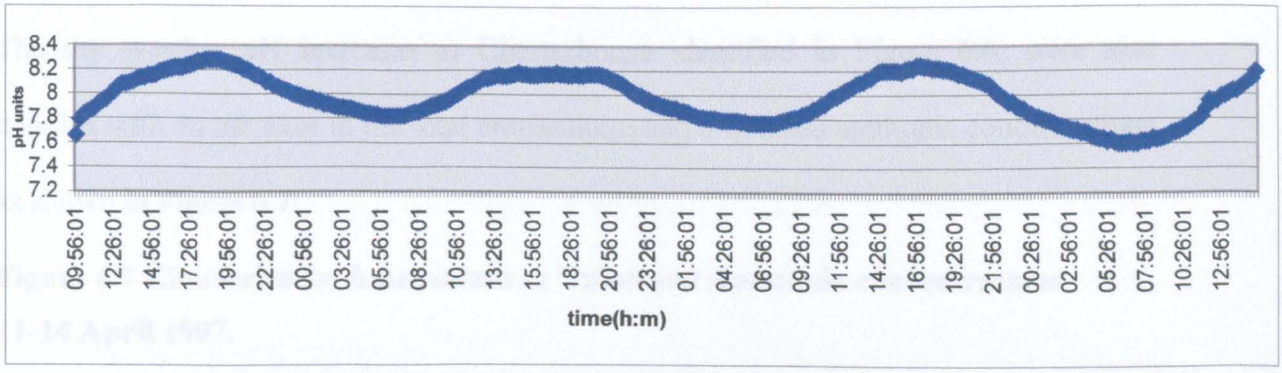
The DO levels generally reduced following storm events, but the main impact of wet weather discharge to the River Sherbourne was to diminish the diurnal pattern of DO saturation recorded during dry weather. The level of DO saturation was generally higher upstream of the city centre, above the urban stormwater inputs from the culverted watercourses identified in Figure 3.2. DO saturation was reduced from around 50-90% to a diurnal variation of 45-80 %, with minimum levels below 10% recorded on occasion, following rainfall, as identified in Section 5.2. Immediately after a rainfall event the diurnal variation was lost for up to 2 days, with recovery following continued rainfall, or a period of dry weather. The ammonium levels also showed a consistent diurnal rhythm, with peaks of greater than 3 mg l^{-1} at around 17:00 hours each day, as shown in Figure 6.4:

Figure 6.4 Ammonium concentration during a period of dry weather, 1997, in the River Sherbourne at Charterhouse (11-14 April 1997)



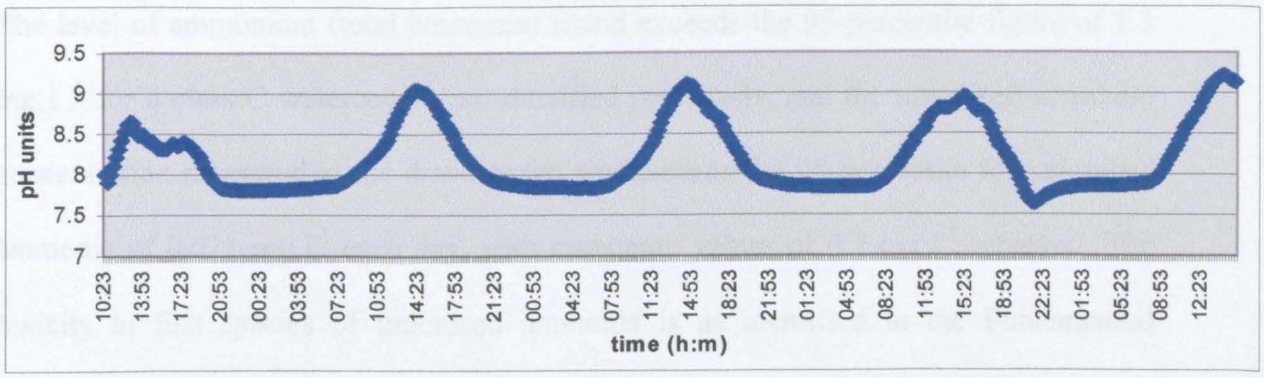
The influence of algal populations in the watercourse in dry weather (11-14 April 1997) was shown in the diurnal rhythm for pH recorded during long term monitoring runs. During the hours of sunlight in dry weather, pH increases at the Rudge Road monitoring point by almost 1 pH unit as carbon dioxide is absorbed to enable photosynthesis, and falls again during the hours of darkness, as CO_2 is released into the water during algal respiration, as shown in Figure 6.5:

Figure 6.5 Diurnal pH variations at Rudge Road 11-14 April 1997



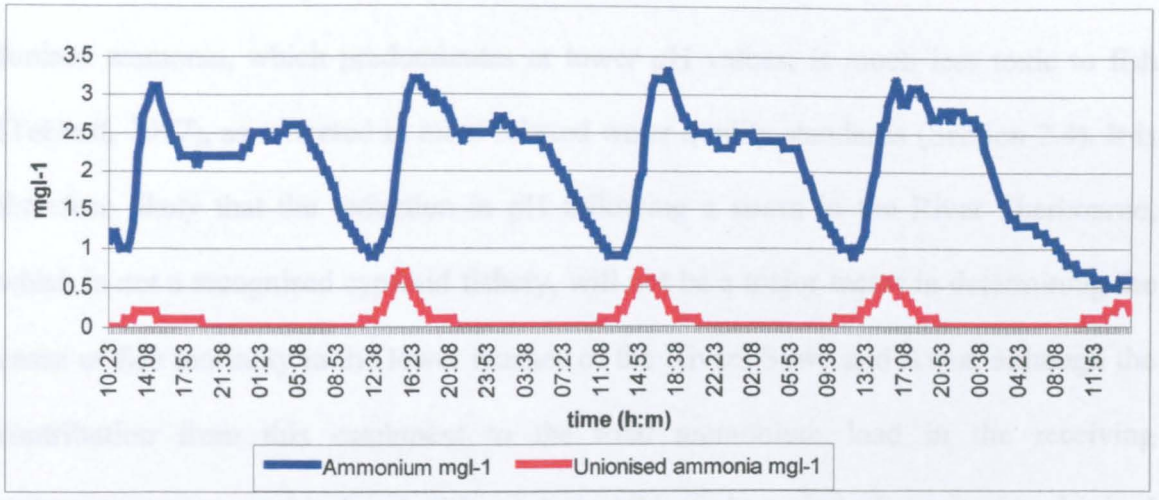
It would be expected that diurnal variation for pH and DO measurements downstream of the city centre culvert would be diminished in the absence of sunlight and photosynthetic activity, but this does not appear to be the case. The culverted section is relatively short, and there is a length of open shallow watercourse immediately before the downstream monitoring points, which would allow the resumption of algal activity, as shown in Figure 6.6:

Figure 6.6 Diurnal pH variations at Charterhouse 11-14 April 1997



The cumulative effect of algal activity below the culverted section, in addition to that measured upstream, will cause an increase in the amount of carbon dioxide utilised by the algal population in the watercourse, and thereby increase the pH levels at the downstream monitoring point. The possible introduction during daylight hours of alkaline discharges, arising from domestic and industrial misconnections during the day, may also be a contributory factor. A comparison of pH levels upstream and downstream of the city during the featured post remedial monitoring runs is made in Section 7.3.3. The dry weather pH increases at Charterhouse identified in Figure 6.6, were also coupled with an increase in the total ammonium, and unionised ammonia concentrations as shown in Figure 6.7:

Figure 6.7 Charterhouse Ammonium & Unionised Ammonia concentrations 11-14 April 1997.



The level of ammonium (total ammonia) found exceeds the 95-percentile figure of 1.3 mg l^{-1} for a class C watercourse, as identified previously, and the unionised ammonia concentration measured at the downstream site exceeds the 95-percentile for unionised ammonia of 0.021 mg l^{-1} each day, with maximum values of 0.7 mg l^{-1} achieved. The toxicity to fish species of unionised ammonia is as identified in the Fundamental Intermittent Standards suggested by the UPM process, as given in Table 2.14

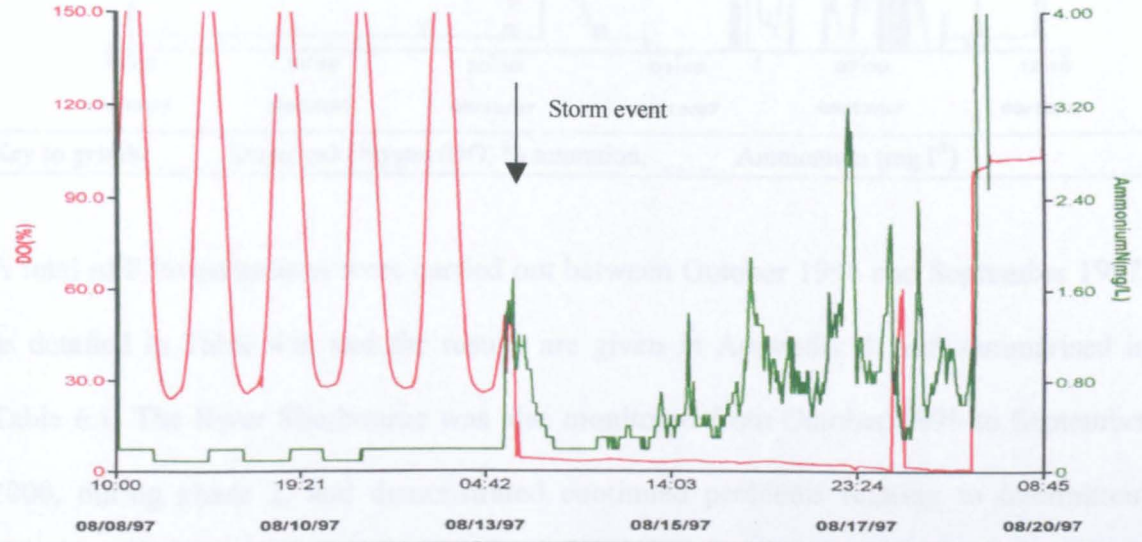
(Foundation for Water Research, 1993), and discussed in Section 2.5.1. Concentrations are upper thresholds, which apply when DO levels are above 5 mg l^{-1}. The thresholds also assume pH is above 7, and temperature is above 5^0C. The toxicity of un-ionised ammonia approximately doubles with a unit drop in pH and a 10^0C drop in temperature (Foundation for Water Research, 1993). The unionised ammonia levels found during this phase of the research were far in excess of the fundamental intermittent standard maximum levels, and although the daily concentration maximum in dry weather was maintained for only 45 minutes at a time, even the yearly return figure of 0.250 mg l^{-1} was breached on a daily basis, as a result of the discharges from the culverted feeder streams or discharges directly made into the culverted section of the watercourse at this time. A decrease in pH, coupled with an increase in un-ionised ammonia, could present a potential risk to fish species.

Ionised ammonia, which predominates at lower pH values, is much less toxic to fish (Tebbutt, 1997), as reflected in more relaxed water quality standards (Section 2.4). It is therefore likely that the reduction in pH following a storm in the River Sherbourne, which is not a recognised cyprinid fishery, will not be a major factor in determining the cause of fish mortality in the lower reaches of the Rivers Sowe and Avon, although the contribution from this catchment to the total ammonium load in the receiving watercourses appeared to be significant during this early period of monitoring. Ionised ammonium concentrations were generally found to be higher downstream of the city, indicating unknown pollution sources from the culverted streams discharging to the River Sherbourne.

One of the most significant monitoring runs was that carried out between 8 August 1997 and 20 August 1997, on the main River Sherbourne. The River Sherbourne at Charterhouse shows the impact of a storm event on water quality. Prior to the storm of

13 August there was a wide diurnal variation of Dissolved Oxygen concentrations observed, ranging from 160% in the late afternoon to below 30% at around midnight. Following the storm event, the Dissolved Oxygen fell to around 0% for 5 days before recovering to normal levels. The ammonium increased from around 0.1mg l^{-1} prior to the storm, to a peak of 3.2mg l^{-1}, 4 days after the start of the event, as shown in Figure 6.5:

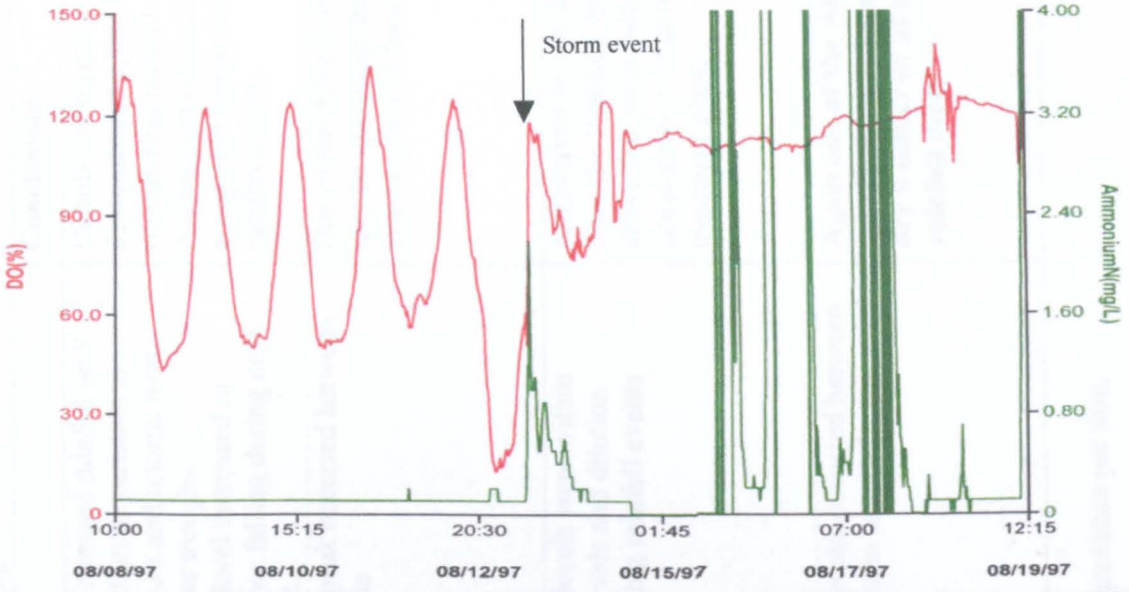
Figure 6.8 Continuous monitoring results for Charterhouse 8-20 August 1997



Key to graph: ____ Dissolved Oxygen (DO) % saturation, ____ Ammonium (mg l^{-1})

The River Sherbourne upstream, at Waveley Road, also showed a wide diurnal variation in Dissolved Oxygen prior to the storm (Figure 6.9), although the minimum concentration was around 50% saturation. Immediately following the storm, the Dissolved Oxygen decreased to around 10% saturation, but returned to pre-storm levels within 24 hours. The Waveley Road monitoring point is in an urban catchment, and is downstream of a consented pumping station storm overflow at Park Drive in the lower reaches of the Pickford Brook (Figure 3.2), but is upstream of the Albany Road CSOs and the City centre.

Figure 6.9 Continuous monitoring results for Waveley Road 8-20 August 1997



Key to graph: _____ Dissolved Oxygen (DO) % saturation, _____ Ammonium (mg l^{-1})

A total of 8 investigations were carried out between October 1996 and September 1997, as detailed in Table 4.6, and the results are given in Appendix 4, and summarised in Table 6.1. The River Sherbourne was also monitored from October 1999 to September 2000, during phase 2, and demonstrated continued problems relating to intermittent pollution and urban runoff, as detailed in Table 6.2, with high ammonium concentrations upstream and downstream of the city, and major disruption to the natural DO diurnal rhythm following rainfall events. The use of automated samplers, in combination with the continuous monitors, also allowed heavy metals and phosphate analysis, and a number of possible trade effluent sources were identified as a result.

Table 6.1 Investigation into River Sherbourne Phase 2 Albany Road early data (1996 to 1997).

Date	Location	Results	Comments	Conclusions
Run 1 3/10/96 to 14/10/96 (4-14 Oct Rudge Rd)	Waveley Road	Dissolved Oxygen readings show diurnal variation from 60 to 90 % saturation after initial disruption following 4.5 mm storm event. Minimum DO drops consistently below 50% after 9 October. The results are given in full in appendix 4.1	Following prolonged rainfall on 9 October the diurnal variation is temporarily lost and returns with slightly deeper troughs. Ammonium level increased to 0.7mgl^{-1} before falling during next rainfall event.	Dissolved Oxygen probe demonstrated a small impact on the river during rainfall. Ammonium concentration within acceptable limits and diluted by rainfall events.
	Rudge Road	Ammonium concentration increases after first rainfall event with a peak to 1mg l^{-1} after the second. The concentration then peaks to a maximum of 2.2 mg l^{-1}. on 11 October. The results are given in full in appendix 4.1	Ammonium peak occurred between rainfall events	One of the Albany Road overflows may be operating during dry weather or as a result of local rainfall event
Run 2 16/10/96 to 28/10/96	Waveley Road	Before the first rainfall event some peaks of Ammonium were identified at around 1.7mg l^{-1}. During the first rainfall event this value was reduced to around 0.9 mg l^{-1}. The diurnal pattern for DO was disrupted by storm events. The results are given in full in appendix 4.2	Ammonium levels were within acceptable levels and dilution occurred during rainfall events	Ammonium levels detected arise from the Pickford Brook catchment above this point which has a high concentration of private sewage treatment plants.
	Rudge Road	Ammonium peaks up to 2.8 mg l^{-1} were identified during rainfall events. An increase of Ammonium to over 2.5 mg l^{-1} occurred between rainfall events. The results are given in full in appendix 4.2.	Ammonium peaks occurred between rainfall events to unsatisfactory levels.	Again **one of the Albany Road overflows may be operating during dry weather or as a result of local rainfall event**

Key to Table: DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 6.1. Investigation into River Sherbourne Phase 2 Albany Road early data (1996 to 1997).

Date	Location	Results	Comments	Conclusions
Run 3 1/11/96 to 12/11/96	Waveley Road	One large $NH_4^+(N)$ spike to over 4 mg l^{-1} occurred early on 4 November accompanied by a dramatic dip to 0% saturated Dissolved Oxygen. DO recovered quickly to diurnal variation with levels to below 10% saturation at times. The results are given in full in appendix 4.3	Suspect results for Ammonium but matched at Rudge Road.	Probes may have been covered in debris following storm event on 3 November or there may have been a sudden surge of Ammonium from an unidentified pollution event.
	Rudge Road	Ammonium at 0.5 –1.0 mg l^{-1} except for spike in excess of 4 mg l^{-1} on 4 November as at Waveley Road The results are given in full in appendix 4.3.		Ammonium spike may have indicated an overflow at Park Road pumping station 5km upstream. On 3 November or local event/ pollution incident.
Run 4 12/11/96 to 26/11/96	Waveley Road	Ammonium peaks to 0.5 mg l^{-1} on 16 November and 0.8 mg l^{-1} on 19 November during rainfall events but maximum peak of 1.3 mg l^{-1} on 22 November unrelated to storm event. DO average 75% saturation. Minimum 50% saturation. The results are given in full in appendix 4.4.	Ammonium within acceptable limits for watercourse.	Third peak, coincident with DO dip may be due to local rain event not identified at Finham. No major contamination identified.
Run 4 12/11/96 to 20/11/96 only	Rudge Road	Dissolved Oxygen levels fell to an average 0f 40% saturation after the first rainfall event increasing to 60% during prolonged rainfall after 17 November. Ammonium levels increased for 3.5 days after 17 November peaking at 4.5 mg l^{-1} The results are given in full in appendix 4.4.	Unacceptable levels of Ammonium reached during rainfall periods.	**Unsatisfactory concentrations of $NH_4^+(N)$ following operation of Albany road storm overflows.**

Key to Table: DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 6.1. Investigation into River Sherbourne Phase 2 Albany Road early data (1996 to 1997).

Date	Location	Results	Comments	Conclusions
Run 5 2/4/97 to 8/4/97	Rudge Road	Following a 1mm rainfall event on 4 April DO diurnal variation ceased until after the rainfall event on 6 April. $NH_4^+(N)$ max 15mg l^{-1}during first storm event and 10 mg l^{-1} during the second The results are given in full in appendix 4.5.	Marked increase in ammonium during rainfall events	Suspect Albany Road storm overflows operating unsatisfactorily.
	Charterhouse	3 April - ammonium peak of 15 mg l^{-1} Turbidity increased during rainfall events. The pH fell to <4 during the first storm The results are given in full in appendix 4.5.	The ammonium peak occurred during dry weather. Oxygen saturation fell to an average of only 20% after the storm period though diurnal variation was maintained	**Ammonium source probably arising from culverted watercourses below Rudge Road. Further investigation required**
Run 6 11/4/97 to 14/4/97 **No storms**	Waveley Road	The $NH_4^+(N)$ concentration stayed below 1mg l^{-1} except for 2 small peaks to max 1.1mg l^{-1}. DO showed diurnal variation. The results are given in full in appendix 4.6.	Dissolved Oxygen fell slowly with no diurnal variation. Turbidity peak unexplained on 12-13 April.	**No rainfall during this run. No major contamination identified.**
	Rudge Road	Ammonium peaks on 12 and 13 April to 1.4 and 2 mg l^{-1} respectively The results are given in full in appendix 4.6.	Unusual dry weather peaks detected.	**Suspect unsatisfactory operation of one or more storm overflows at Albany road.**
	Charterhouse	Ammonium peak identified each day at around 17:00 hours to a maximum of 3.2 mg l^{-1} The results are given in full in appendix 4.6.	Average 2.5 mg l^{-1} with daily increases in ammonium during dry weather. Unionised ammonia peaked to a max. of 0.7 mg l^{-1}.	**Denotes regular dry weather contamination from culverted watercourses below Rudge Rd**

Key to Table: DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 6.1 Investigation into River Sherbourne Phase 2 Albany Road early data (1996 to 1997).

Date	Location	Results	Comments	Conclusions
Run 7 8/8/97 to 19/8/97	Waveley Road	Large diurnal variation in Dissolved Oxygen (10 – 130% saturation) until storm on 13 August. Ammonium peak to 2.2 mg l^{-1} before probe failed. The results are given in full in appendix 4.7	Ammonium probe showed erratic results after 16 August.	Possible probe failure or covered in debris.
8-20/8/97	Charterhouse	Large diurnal variation in Dissolved Oxygen (25-150% saturation) until storm on 13 August when levels fell to less than 5%. Ammonium peak to 3.2 The results are given in full in appendix 4.7.	Oxygen 'flat-lined' following storm event after dry weather diurnal pattern obtained. Ammonium concentration storm related	Dramatic impact demonstrated on DO and ammonium levels downstream of the City.
Run 8 2/9/97 to 16/9/97	Gosford Street (Just above Charterhouse)	Dissolved Oxygen calibration suspect. Ammonium levels rose to 5 mg l^{-1} following second rainfall period and 2.4 mg l^{-1} following the first The results are given in full in appendix 4.8.	Position moved from Charterhouse due to proximity of school and likelihood of vandalism. Gosford St more secure site	Ammonium concentrations rainfall-related showing contamination downstream of the city following storms. Final ammonium peaks in post-storm dry period denoted misconnections in culverts.

Key to Table: DO – Dissolved Oxygen, $NH_4^+(N)$ – Total ammonia (ammonium), mg l^{-1} – milligrammes per litre.

Table 6.2 Data Collection Pre-remedial Results from October 1999 to September 2000

Run No. & Date	Location	Results	Comments	Conclusion
Run 1	Vincent Street	Monitor failure – no results		Result of vandalism
1-Oct-99 to 10-Oct-99	Gulson Road	Following large initial storm (8 hours) Max. 6 mm hr^{-1} DO saturation diurnal variation was lost for 6 days falling gradually from 90% to <40% before returning to variable pattern of 10-70%. NH_4^+(N) peaked to 0.9 mg l^{-1} during initial storm, falling to 0.2-0.4 mg l-1 for rest of monitoring period. The pH remained fairly constant at 7.2-8.0 becoming 7.4-7.6. SC fell from 0.6 to zero after initial storm rising to 0.6 over 5-6 days. Fell slightly during second event to 0.3 µS cm^{-1}. The results are given in full in appendix 5.1.	Example of first flush (Sections 2.2 and 7.3.3)	DO, SC, NH_4^+(N) all affected by storm event with diurnal variation lost. No indication of whether source was upstream or downstream of city centre as upstream monitor failed.
Run 2 2-Mar-00 to 3-Mar-00	Humber Avenue Auto1	BOD 3.5 mg l^{-1} falling to range of 2-3 mg l^{-1} with peak during 3mm hr^{-1} storm (total rainfall 5mm) at >4 mg l^{-1} falling to 2.5-3.5 post storm. NH_4^+(N) not detected throughout SS 10-20 mg l^{-1} rising to 50 mg l^{-1} during peak rainfall with final increase to >120 mg l^{-1} post storm. No o-P detected Initially pH @ 8.0- 8.2 falling to 7.8 during peak rainfall recovering to around 8.0 post storm. Cd not detected until peak rainfall @ > 9 µg l^{-1} Cr 1.5-2.0 µg l^{-1} rising to > 2 µg l^{-1} tailing off to 1.5 µg l^{-1}. Cu 18 µg l^{-1} falling to 5 µg l^{-1} before reaching peak during rainfall @ 15 µg l^{-1}. Returning to 5 µg l^{-1} post storm Zn high initially at >200 µg l^{-1} falling to 20 µg l^{-1} before peaking at 50 µg l^{-1} and then falling to 20 µg l^{-1}. Ni not detected. The results are given in full in appendix 5.2	No continuous monitors available Auto sampling at Humber Avenue only.	Sample period began after period of rain (0.5 mm max). Single rainfall event during sampling period (3 mm hr^{-1} max, 5 mm total rainfall) BOD, SS, pH, Cr, Cu, Zn all impacted by rainfall event. No impact on ammonium, Cd or Ni. Not likely that pollution source was due to combined sewer outfall as no NH_4^+(N) detected.
Run 3 10-Mar-00 to 11-Mar-00	Meadow Street Auto2	Auto 2 Run gave only 2 samples		2 results only

Key to table: DO- Dissolved Oxygen, NH_4^+(N)- Total ammonia (ammonium), mg l^{-1}- milligrammes per litre, SC- Specific Conductivity, o-P Orthophosphate

Table 6.2 Data Collection Pre-remedial Results from October 1999 to September 2000

Run No. Start Date	Location	Results	Comments	Conclusion
Run 4 15-Mar-00 to 16-Mar-00	Meadow Street Humber Avenue Continuous monitors	DO at Meadow Street showed steady decline form 160% to 90% increasing during afternoon (algal activity) to 120%. DO at Humber Ave showed marked diurnal variation to 108% max. falling to <95 % with an increase at 10:30 hrs 16 March to 105%.NH_4^+(N) zero until unknown event rising to 70 mg l^{-1} at Meadow Street and 3.5 mg l^{-1} at Humber Avenue. Slight diurnal variation of pH (8.2- 8.4) with increase to 8.7 during 'event' falling to 7.9. SC constant at 0.6 µS cm^{-1} at Meadow St., 0.55 @ Humber Avenue falling to zero at both sites at around 09:45 hours and 10:00 hours respectively on 16 March. The results are given in full in appendix 5.3.1.	Dry weather throughout monitoring period Unknown event occurred @ 10:30 hrs on 16 March	Unknown event may have been sewer blockage giving rise to overflow, misconnection or illegal trade effluent discharge. Ammonia results suggest that it may have been chemical discharge rather than sewage related, as no great increase in BOD or DO reduction. This ties in with pH increase at Meadow Street Alkaline Pine strippers located upstream of Meadow Street and Albany Road CSO outfall. Identified as discharger to Albany Road foul sewerage. No confirmation of source possible.
	Humber Avenue Auto 3 (samples)	BOD 1.5-2.0 mg l^{-1} with slight peak at 09:00 hours 16 March to >2 mg l^{-1} NH_4^+(N) not detected throughout sampling period. SS peak (2 samples) at 18 mg l^{-1} falling to range of 3-6 mg l^{-1}. Slight increase to 12 mg l^{-1} at 13:00 hours on 16 March. Cd showed 2 peaks to 0.1 µg l^{-1} during dry weather. Otherwise none detected. Cr constant in range of 2.5-3.0 µg l^{-1}. Cu constant in range of 2.5 – 3.0 µg l^{-1} Zn constant in range of 8.0- 9.0 µg l^{-1} Ni showed an early dry weather result of 10 µg l^{-1}. Otherwise not detected. The results are given in full in appendix 5.3.2	Samples at Humber Avenue only Spot sample may have missed NH_4^+(N) peak.	
Run 5 23-Mar-00 to 24-Mar-00	Humber Avenue Auto 4	BOD <5 mg l^{-1} to 38 mg l^{-1} peak during peak rain, falling to <10 mg l^{-1} post storm. Increase following lost sample to 18 mg l^{-1}. Ammonia not detected initially rising to 1.7 mg l^{-1} during rainfall, falling to zero over 11 hours during dry period. SS <5 mg l^{-1} rising to peak of 120 mg l^{-1} before falling post storm to 5 mg l^{-1}. > 20 mg l^{-1} following lost sample (2nd rain event) No o-P detected. The pH fell from 8.2 to 7.1 before return to 8.0. Last sample @7.5. Cd zero to 0.9 peak falling over 11 hours to zero. Last sample <10 µg l^{-1}. Cr peak @ 60 µg l^{-1}. Last sample @ <10 µg l^{-1}Cu and Zn @ peak of 60 & 150 µg l^{-1} respectively, falling to <10 and <25 µg l^{-1}. Ni peak @ 22 µg l^{-1} levelling to zero. The results are given in full in appendix 5.4.	Initial rainfall to 2.5 mm peak with total of 4mm over 4 hours No continuous monitors used. Sample lost during 2nd (1mm) rainfall event.	Rainfall impacted on BOD, NH_4^+(N), SS, pH, Cd, Cr, Cu, Zn and Ni. No impact on o-P. All concentrations increased apart from pH level which fell during storm event.

Key to table: DO- Dissolved Oxygen, NH_4^+(N)- Total ammonia (ammonium), mg l^{-1}- milligrammes per litre, SC- Specific Conductivity, o-P – Orthophosphate

Table 6.2 Data Collection Pre-remedial Results from October 1999 to September 2000

Run No. Start Date	Location	Results	Comments	Conclusion
Run 6 29-Jun-00 to 9-Jul-00	Meadow Street Humber Avenue	DO diurnal variation reduced following initial storm to 60- 80 % saturation range at Meadow Street DO readings dropped to zero for 2 days at Humber Avenue following storm event returning to variation of <5% to 100% for rest of monitoring period. Rainfall event on 6 July also reduced DO to zero before recovery, over next 18 hours, to 80%. Ammonia peaked @ 0.8 mg l^{-1} @ Meadow Street and 2.5 mg l^{-1} @ Humber Avenue with Av. values 0.1 and 0.4 mg l^{-1} throughout remaining monitoring period and only minor peaks identified. The pH was less erratic at Meadow St, but showed a greater storm impact falling from 7.7 to 6.9 whilst at Humber Avenue it fell from 8.0 to 7.5 during rainfall. SC, which is generally higher at Humber Avenue, fell from 0.6 to 0.1 µS cm^{-1} @ Meadow Street, and 0.65 to 0.15 µS cm^{-1} at Humber Avenue The results are given in full in appendix 5.5.	Continuous monitors at both sites only. Initial storm peak @ 7 mm hr^{-1} (total rainfall 13.5 mm over 5 hours) Eight rainfall events in all during monitoring period.	Large initial storm event impacted at both sites and probe may have failed at Humber Avenue or DO levels may have crashed as a result of the storm, as each following rainfall event also reduced DO to zero temporarily. pH at Humber Avenue was generally higher than at the upstream point. Sharp decreases in SC during each rain event with recovery after 12- 20 hours to 0.6 µS cm^{-1}.
Run 7 28-Sep-00 to 29-Sep-00	Meadow Street Humber Avenue Continuous monitors Humber Avenue Auto 5	DO % saturation showed no impact from rainfall at either site. Slight diurnal rhythms not disrupted with average of 85% saturation at Meadow Street and a range of 80-85% at Humber Avenue. NH_4^+(N) fairly constant over period of monitoring with initial 0.6 falling to 0.3 mg l^{-1} at Meadow Street and 0.7 down to 0.4 mg l^{-1} at Humber Avenue. Slight diurnal increase in pH at both sites (7.94 to 8.01 at Meadow St. and 7.8 to 7.95 at Humber Avenue) with slight decrease from 7.8 to 7.68 during the rain event. SC increased steadily at both sites (0.49 to 0.57 µS cm^{-1} at Meadow Street and 0.55 to 0.64 µS cm^{-1} at the downstream site). Slight peak to 0.61 µS cm^{-1} during rainfall at Humber Avenue. BOD average 0.25 (steady) rising to 9 mg l^{-1} in last sample.NH_4^+(N) initially 0.26 falling to 0.1 mg l^{-1} average with little variation. The o-P concentration steadily decreased from 0.29 mg l^{-1} to approximately 0.16 mg l^{-1} with no impact from the rain event. Sampled pH increased slightly from 8.0 to 8.1 before and during rainfall event before falling to 8.0 in the morning and rising again to 8.1 during daylight. The results are given in full in appendix 5.6.1 and appendix 5.6.2.	One 1.5 mm event at rainfall gauge (Coventry STW, Finham), which may not have impacted greatly on the area monitored. No impact from rain event on depth flow or velocity at Humber avenue during rainfall event, with steady increase over monitoring period until sharp increase at end of run possibly indicating rainfall on perimeter of drainage area. Sampled pH minor increase not shown by monitors. May be a result of reaching equilibrium before pH testing in lab.	NH_4^+(N) generally higher and pH generally lower at Humber Avenue monitoring site. No major impact identified by rainfall event.

Key to table: DO- Dissolved Oxygen, NH_4^+(N)- Total ammonia (ammonium), mg l^{-1}- milligrammes per litre, SC- Specific Conductivity, o-P – Orthophosphate

6.1.2 Pre-remedial results

The focus of investigation during the latter part of Phase 2 was on the stretch of River Sherbourne immediately downstream of the Hope Street outfall from the six Combined Sewer overflows (CSOs) located in Albany Road (Figure 4.10), as discussed in Section 4.4.2. These continuous monitoring investigations, carried out between October 1999 and September 2000, identified that there were intermittent pollution sources impacting on the water quality of the River Sherbourne in dry weather, and during rainfall events. Total ammonia peaked to levels far in excess of the GQA upper 90-percentile limit of 1.3 mg l^{-1}, and there was disruption of the natural DO diurnal variation, and percentage saturations below the minimum 10-percentile limit of 60% saturation. The results are summarised in Table 6.2, presented graphically in Appendix 5, and discussed in Section 6.2.2 below.

6.2 Conclusions – Phase 2.

6.2.1 Early data, October 1996 to September 1997 (8 runs)

During the early monitoring runs between October 1996 and September 1997, the DO levels generally reduced following storm events, but the main impact of wet weather discharge to the River Sherbourne was to diminish the diurnal pattern of DO saturation recorded during dry weather. The level of DO saturation was generally higher upstream of the city centre, above the urban stormwater inputs from the culverted watercourses (Figure 3.2), as would be expected upstream of a polluting discharge (Tebbutt, 1998; Mason, 1996). DO saturation was reduced from around 50-90% to a diurnal variation of 45-80 %, with minimum levels below 10% recorded on occasion following rainfall as identified in Section 6.1.1. Immediately after a rainfall event, the diurnal variation was lost for up to 2 days, with recovery following continued rainfall, or a period of dry weather. Ammonium levels generally increased following rainfall events, as identified

in Section 6.1.1 and Appendix 4. An average of 1.5 mg l^{-1} following rainfalls was not uncommon, with levels rising to greater than 4 mg l^{-1} during 6 of the 8 storms monitored, during 1996 to 1997. The other 2 storms monitored during this period achieved levels of greater than 2 mg l^{-1} in the receiving watercourse, with the monitored event at Rudge Road on 2 April 1997 giving a mean concentration of 5.8 mg l^{-1} above the city centre (downstream of the Albany Road Combined Sewer Overflows outfall as identified in Figure 4.5). The continuous monitor results identified that the smaller culverted watercourses draining to the River Sherbourne also discharged high concentrations of total ammonia, during dry weather periods, as well as during rainfall events. The data collected in relation to the Albany Road CSOs was presented to Severn Trent Water Ltd to encourage a review of the operation of the overflows, and to consider whether removal or modification was possible. Identification of intermittent discharges in culverts discharging downstream of the CSO outfall prompted the monitoring investigations (Phase 1) described in Chapters 4 and 5.

In the Early data collection part of Phase2, some of the results were not transferable to a database spreadsheet, and statistical analysis of the trends and relationship between different parameters has not been undertaken. Only the results for the wet weather investigation on 2 – 8 April 1997, and the dryweather monitoring from 11-14 April 1997, were analysed for rank correlation with significance to 95% and 99% levels using the Spearman's test as discussed in Chapter 4. The correlation data is summarised in Tables 6.3 and 6.4.

The results for total ammonium concentrations show a highly significant positive correlation between monitoring points ($p>0.01$) during the storm event on 2 April 1997, and with turbidity ($p>0.01$), and a highly significant negative correlation with DO, specific conductivity and downstream pH levels (correlation coefficient -.511, $p>0.01$),

as shown in Table 6.3. During the storm event on 2 April 1997, the pH at Rudge Road increased during the storm (Appendix 4.5), which was unusual in that pH values were generally found to be higher downstream of the city centre following rainfall events. The upstream pH was higher on this occasion, with a mean of 7.92 compared to a mean of 7.06 at Charterhouse, below the urban drainage area input. Analysis of results for the whole period of investigation gave a positive correlation between DO and pH downstream of the city ($p>0.01$) suggesting that pH levels generally decreased with a reduction in DO during the rainfall event, as a result of urban runoff.

Operation of the Albany Road overflows had a direct impact on both ammonium and pH values, perhaps through the introduction of trade effluent components in the raw sewage discharged (one of which was later identified as an alkaline pine stripping process), although generally, the introduction of urban runoff to the River Sherbourne had an opposite effect on pH values, with levels decreasing during storm events as identified in Table 6.2.

As the combined sewer overflows were eventually found to be unsatisfactory, and by no means operating within design criteria, it was not possible to identify which of the six overflows contributed to the pollutant load at any one time during a storm event, or at what magnitude of rainfall an overspill from each or all of the overflows occurred. During the dryweather event on 11-14 April, the ammonium concentrations showed a highly significant ($p>0.01$) correlation with specific conductivity, and a highly significant negative correlation with DO, pH and unionised ammonia (Table 6.4).

In general as ammonia increased, DO percentage saturation levels, and pH decreased. This pattern is similar to that measured during the surface water investigations carried out in Phase 1 (and in the later post-remedial river monitoring runs). A dry weather investigation is useful as it indicates the impact of non-point sources (or more widely

distributed point sources) on this urban watercourse more clearly, without the influence of a major wet weather point discharge such as the Albany Road Combined Sewer Overflows outfall. DO showed a highly significant correlation with pH ($p>0.01$) in dry weather, which could be due to the impact of algal activity producing oxygen, giving increased DO saturation and pH values during daylight hours, with a reduction in both measurements overnight.

The results confirm that urban point sources act as a significant contributor to water quality degradation (Brezonik and Stadelmann, 2002), and that urban runoff contains a variety of pollutants, exerting a large pollutant load to receiving watercourses (Whipple and Hunter, 1981; Characklis and Weisner, 1997). This pollutant load will include heavy metals, dissolved and SS, organic animal and vegetable matter, silt, bacteria, ammonia and ammonium salts (Novotny and Olem, 1994). The ammonium concentrations recorded indicate that the main impact on water quality on this urban stretch is from the CSOs located at Albany Road, as shown in Figure 4.5. The reduction in DO, as described by Mason (1996) and interruption of diurnal variation (Klein, 1972), accompanied by rises in ammonium (Clifforde and Williams, 1998) indicate that sewage contamination was regularly occurring in the watercourse, especially during heavy rainfall. Harremoës (1981) suggested that the degradation of organic matter takes place in 2 stages; an instantaneous degradation by heterotrophic bacteria, and delayed depletion due to sediment oxygen demand, which can give reduced oxygen saturation over a period of days. This was evident in the River Sherbourne, with disruption in diurnal variation in the River Sherbourne, and oxygen depletion in the lower reaches of the River Sowe and River Avon, lasting for several days. The secondary effect may be the result of oxygen demand by heavy sediment deposits in culverted watercourses and drainage systems feeding to the urban watercourse (Deletic, 1998).

Table 6.3 Early data 1997 a) 2-8 April 1997 Spearman's rank correlations summary

US DO% saturation	US DO% sat^{n}									
US NH_3 N mg l^{-1}	-0	US NH_3 N mg l^{-1}								
US SC µS cm^{-1}	-1	-0	US SC µS cm^{-1}							
US Turbidity NTU	1	-0	-1	US Turbidity NTU						
US pH	-1	0	1	-1	US pH					
DS DO% saturation		-1	1	-0	1	DS DO% saturation				
DS NH_3 N mg l^{-1}		1	-1	1		-1	DS NH_3 N mg l^{-1}			
DS SC µS cm^{-1}								DS SC µS cm^{-1}		
US Turbidity NTU		1	-1		0	-1	0		DS Turbidity NTU	
DS pH	1	-1		1		1	-1		-1	DS pH

Key to table:
US = Upstream of city
DS = Downstream of city
NTU = Nephelometric Turbidity Units
SC= specific conductivity

Key	Storm 1=Highly Significant; 0=Significant Highly Significant ($p \leq 0.01$); 0=Significant $p \leq 0.05$	Positive correlation	negative correlation	No result or no correlation

Table 6.4 early data b) 11-14 April 1997 (dryweather) Spearman rank correlations summary

US Temp	US Temp°C																				
US pH	1	US pH																			
US SC	-1	-1	US SC µS cm^{-1}																		
US salinity				US salinity mgCl																	
US pressure	-1		1		US pressure																
US NH_4^+(N)	-1	-1	1		-1	US NH_4^+(N) mg l^{-1}															
US NH_3N							US NH_3N mg l^{-1}														
US DO%	1	1	-1		-1	-1		US DO% sat^n													
US DO mg l^-	1	1	-1		-1	-1		1	US DO mg l^{-1}												
US turbidity	1	-1	-0		-1	1		1	1	US turbidity (NTU)											
DS Temp	1	1	-1		-1	-1		1	1	1	DS Temp°C										
DS pH	1	1	-1		-1	-1		1	1		1	DS pH									
DS SC	1	1										-1	DS SC µS cm^{-1}								
DS salinity	1	1			-1			1	1		1		1	DS salinity mgCl							
DS pressure	-1	0	1		1	-1		-1	-1	-1	-1	-1		-1	DS pressure						
DS NH_4^+(N)	1	1				-0						-1	1	1		DS NH_4^+(N) mg l^{-1}					
DS NH_3N		1	-1		-1	-1		1	1		1	1		1	-1		DS NH_3N mg l^{-1}				
DS DO%	1	1	-1		-1	-1		1	1		1	1	-1	-1		-1	1	DS DO% sat^n			
DS DO mg l^{-1}	1	1	-1		-1	-1		1	1		1	1	-1	-1		-1	1	1	DS DO mg l^{-1}		
DS turbidity	1	-1	-1		-1	1		1	1	1	1			1	-1				US turbidity (NTU)		

Key:
1=Highly Significant, 0=Significant results
minus value denoted negative correlation
Highly Significant ($p \leq 0.01$); 0=Significant $p \leq 0.05$
DS Downstream values
US Upstream values
SC Specific Conductivity
DO Dissolved Oxygen
NH_4^+(N) total ammonia (ammonium)
NH_3 N unionised ammonia
NTU= Nephelometric Turbidity Units

6.2.2 Pre-remedial data collection, October 1999 to September 2000

Pre-remedial monitoring runs, between October 1999 and September 2000, identified that on more than one occasion the impact of the Combined Sewer Overflows at Albany Road led to an increase in pH at Meadow Street. Generally the pH recorded downstream was reduced as a result of urban runoff during wet weather, and the pH at Meadow Street was generally slightly lower than that recorded downstream of the city, even when the storm event was having an impact in reducing the pH at both sites. The reason for this is unclear, and points to the possibility that there is an unknown trade effluent, or other unknown discharge, which consistently lowers the pH at Meadow Street, or raises the pH at Humber Avenue in non-storm conditions. The cumulative effect of algal populations, as discussed in Section 6.1 may be a contributory factor.

The pre-remedial runs involved the use of continuous monitors at sites above and below the city centre, with the inclusion of automated sampling on an hourly basis, which allowed analysis for total metals during a storm event. The results showed a high degree of correlation between the upstream and downstream sites, giving a high level of confidence in the results obtained. The results were consistent with urban runoff identified with findings of other studies (Field *et al.*, 1982; Novotny and Olem, 1994; Bang *et al.*, 1997; Lee and Bang, 2000), as discussed in Section 2.2.

Generally total Cu and Zn concentrations increased during a storm event ($p>0.01$), and to a lesser degree so did total Cr ($p>0.05$). As the storm progressed, BOD, SS and ammonium concentrations consistently showed a highly significant positive correlation with each other (Spearman's rank correlation $p>0.01$). Zn, Cr and Cu all showed a significant positive correlation with SS, which indicates that the total metal concentrations may be linked to particulates in the storm flows. The results for Cd, Ni and total and ortho-phosphate concentrations were relatively few in number, as

concentrations were generally below detectable levels. This makes the statistical assessment of these parameters difficult, and highly significant results can easily be obtained with few results, when undertaking statistical analysis. The results generally showed an increase in these parameters during rainfall events. Specific Conductivity and pH levels again showed a highly significant negative correlation with ammonium and downstream heavy metals as shown in Tables 6.5 and 6.6, and Appendix 5.

During dry weather, as in the run carried out on 15 March 2000 (Auto 3, Appendices 5.3.2 and 5.3.3), the results showed no major peaks or troughs for any of the parameters measured, other than as a result of diurnal variation due to algal activity in the watercourse. Two measurements for Cd were obtained at 0.1μg l^{-1}, which coincided with increases in SS downstream of the city. The cause of this is undetermined; there were two metal finishing companies with direct surface water drainage to the culverted section of the Sherbourne at this time, but no other increases in metals were recorded. During dry weather ammonium levels were continuously monitored, with little variation during the investigation, and sampled ammonium concentrations were below detectable levels at all times. Unionised ammonia was not monitored during this phase of the investigation due to probe failure, and it was not determined whether the daily peaks monitored during the early stages of the research were still present.

The results (Appendix 5) show that rainfall related events during the pre-remediation phase had a significant impact on the River Sherbourne. The local impact of the Albany Road storm overflows and culverted streams was successfully determined by the use of intensive monitoring and sampling surveys. This recorded variability in water quality would not necessarily have been identified in the monthly General Quality Assessment of the watercourse routinely carried out by the Environment Agency.

Table 6.5 Pre-remedial rank correlations (continuous monitor data only considered – pre remedial) See also Auto 1-5 results

US DO%	US DO%									
US NH3	-1-1-1-1-1 -1-0	US NH3								
US pH	111111111 -11	-1-1-1-0-1 -1-1-1-111	US pH							
US TDS	111-1-11 -11-1-1	-1-1-11-1 -1111	111111111 1-1	US TDS						
US Temp	1-11-11-1 1-1	11111-11 1111	-1-11-1-11 -1111	-01111111 -1	US Temp					
DS DO%	111111111 11	-1-10-1-1 -1-1-0	111111111 -11	-1-01-1-1 -11-1-1-1-1	1111-1111 -1-1	DS DO%				
DS NH3	1-1-1-1-1 -1-1-1-1-1	111111111 1	1-1-1-1-1 -1-1011	11111-1-1 111	1111-11- 1111	-0-1-1-1-1 1-1-1-1-1-1	DS NH3			
DS pH	11111111 -1-11	-1-11-1-1 -111	111111111 11	111111111 -1	-111-11-1 1-111	1-111111 11-11	1-11-11-1 -1-01	DS pH		
DS TDS	111-1-1-1 1-1-1-1-1	-1-1-11-1 -1-11	1111111-1	111111111 11	-1111111 -0	-11-1-1-1 -1-1-1-1	111-1-111 1	11111-111 1-1-1	DS TDS	
DS Temp	1010-1-0 -1-1-1	11111-111 110	1-1-11-1-1 -11	11111111	111111111 1	1111-1-1 -0-1-1-1-1	111-11-01 11	111-1-10-1 10	1111111	DS Temp
Depth	1111-1111 -1	111-11111 -1	-1-1-1-1-1 -11-1-11-0	-1-1-1-1-1 -1-1-1-0-11	11111-111 -1	11111111	-1-11-111 1-1-1-1	-1-1-0-11 -1-1-1-1	-1-11-1-1 -1-1-1-11	11111-111 -11

Key	Storm 1=Highly Significant (p≤0.01); 0=Significant p ≤0.05 Dry weather 1=Highly Significant p≤0.01 ; 0=Significant p ≤0.05	100%Consistent trend	90 – 99% consistent trend	80- 89% consistent trend	<80% consistent trend

Key to table:
1 = highly significant positive correlation during single run
-1 =highly significant negative correlation during single run
0 indicates a positive or negative (-0) significant correlation
Numbers in brown indicate a dry weather investigation run
US= Upstream of city; DS= Downstream of city

Table 6.6 Spearman Pre-remedial rank correlations (sheet 1 Auto 1-5 sample correlation with sample parameters– pre remedial)
NB: No sample results for Auto2

sampled													
BOD	BOD												
NH_3N	1	NH_3N											
SS	10		SS										
Ortho-P	0	1		Ortho-P									
pH	-1-1-0	-1	-1-1	-1	pH								
Total Cd	1-1		1-1		-1	Total Cd							
Total Cr	0		1		-0	11	Total Cr						
Total Cu	110		1		-1-1	-1	1	Total Cu					
Total Zn	11		01		-1-1	1	1	11	Total Zn				
Total Ni	1						1	1	1	Total Ni			
rainfall					-0						rainfall		
depth												depth	
TON													TON
Total P													
Total Pb													
Chloride													

Key to table:
1 = highly significant positive correlation during run
-1 = highly significant negative correlation during run
0 indicates a positive or negative (-0) significant correlation
Numbers in brown indicate a dry weather investigation run

Key	Storm 1=Highly Significant p≤0.01; 0=Significant p ≤0.05 Dry weather 1=Highly Significant p≤0.01; 0=Significant p ≤0.05	Consistent trend where more than one result	Dry weather result gives opposite trend	1 significant result or less

Table 6.7 Spearman pre-remedial rank correlations (sheet 2Auto 1-5 samples correlation with continuous monitors where applicable)
NB:No sample results for Auto2.

Continuous / sampled	US DO%	US NH_3N	US pH	US spec.cond.	DS DO%	DS NH_3N	DS pH	DS spec.cond.	US TDS	US Temp	DS TDS	DS Temp
BOD		01				1						
NH_3N		1	-1	-1		1	-1	-1				
SS												
Ortho-P		1	-1	-1		1	-1	-1				
pH		-1		0		-1	1					
Total Cd	-1		-1	1	-1		-1	-1				
Total Cr				0								
Total Cu	0	1	0		1		1	-0				
Total Zn						-0		-1				
Total Ni												
rainfall												
depth									**Key to table:**			
TON									1 = highly significant positive correlation during run			
Total P									-1 = highly significant negative correlation during run			
Total Pb									0 = positive or negative (-0) significant correlation			
Chloride									Numbers in brown = a dry weather investigation run			
									US= Upstream of city; DS= Downstream of city			

Key	Storm 1=Highly Significant p≤0.01; 0=Significant p ≤0.05 Dry weather 1=Highly Significant p≤0.01; 0=Significant p ≤0.05	Consistent trend where more than one result	Dry weather result gives opposite trend	1 significant result or less

Table 6.8 Spearman pre-remedial rank correlations (sheet 3 continuous monitor results including Auto 1-5 where applicable)
NB:No sample results for Auto2

Continuous monitoring														
US DO%	US DO%													
US NH_4(N)	11	US NH_4 N												
US pH	11011	-10-1	US pH											
US spec.cond	1-1	-1	1-01	US spec.cond										
US Temp	1	1	-0	-1	US Temp									
US TDS						US TDS								
DS DO%	111	-11-1	111	-11	1		DS DO%							
DS NH_4N	-11	111	-01-1				-111-1	DS NH_4N						
DS pH	111	-10-1	111	11			-1111	11-1	DS pH					
DS spec.cond	1-00	-1-1-1	11	11	-1		-11-01	11-1	11-11	DS spec.cond				
DS Temp	1		-1	-1	1		1	-1		-1	DS Temp			
DS TDS												DS TDS		
rainfall							1	-11		-0			rainfall	
Rainfall -1 hour	0	0					1	-11					1	Rainfall -1 hour

Key to table:
1 = highly significant positive correlation during run
-1 = highly significant negative correlation during run
0 indicates a positive or negative (-0) significant correlation
Numbers in brown indicate a dry weather investigation run
US= Upstream of city; DS= Downstream of city

Key	Storm 1=Highly Significant p≤0.01; 0=Significant p ≤0.05 Dry weather 1=Highly Significant p≤0.01; 0=Significant p ≤0.05	Consistent trend where more than one result	Dry weather result gives opposite trend	1 result inconsistent	1 significant result or less

Summary

The information gained during this Phase was used to identify that remediation of the Albany Road problem, and investigation of the culverted feeder streams, was required to improve the quality of the River Sherbourne, and resulted in the removal of the unsatisfactory combined sewer overflows as discussed in Chapter 3.

An investigation by Severn Trent Water Ltd in 1999 subsequently identified that the initial overspill calculation of one discharge per year was significantly incorrect, and estimated 15 spills per year from the Albany Road system with a volume of 2300m^3 of untreated storm sewage discharging to the watercourse. The proposal for remediation of the system involved the introduction of one high-level storm relief weir with a carry-forward flow of 850 l s^{-1}. The scheme was designed to reduce the amount of foul sewage spilled to the watercourse during wet weather events, and modelling suggested a proposed overspill frequency of once per year, with a discharge volume of only 25m^3 of diluted sewage effluent, as shown in Figure 3.8.

The Environment Agency and Severn Trent Water Ltd also recognised the need to continue and expand the investigation of culverted feeder streams to remove unknown pollution sources, although no specific funding for this work was identified, other than supporting Phase 1 of this research. The Albany Road surface water sewers were replaced with a single high level overflow and the conversion of one surface water sewer into a secondary foul sewer as described in Section 3.5 and Figure 3.8. Following removal of the combined sewer overflows, the watercourse was monitored upstream and downstream of the city as Phase 3, in accordance with the methodology outlined in Figure 4.1. Continuous monitoring for flow, velocity, and water quality was carried out as discussed in Section 4.5, and shown in Tables 4.1 and 4.7. The results are given in Chapter 7.

Chapter 7 Phase 3 Results

Introduction

Investigations into the water quality of the River Sherbourne, upstream and downstream of the culverted section, continued after the Albany Road Combined Sewer Overflows (Section 3.5) were removed by Severn Trent Water Ltd in September- October 2000, as part of a remediation scheme costing over £400,000 (Figure 3.8). A total of 17 post-remedial investigations (Runs numbered 8-24) were carried out at Meadow Street and Humber Avenue between October 2000 and November 2003, as identified in Figure 4.1 and Table 7.1. Some investigations used continuous monitors, as during the pre-remedial investigation (Phase 2, Section 6.1.2), plus automatic sampling equipment, with analysis for sanitary determinands and heavy metals carried out as discussed below. Rainfall data were collected for the period of each monitoring run at Coventry (Finham) Sewage Treatment Works. Where automated sampling was carried out, the continuous monitoring data and automated sample analysis were matched, with only the short period covered by the sampling operation under consideration for the continuous monitoring data. Where investigations only used continuous monitoring, the period of investigation was extended for up to two weeks. The results from all of the post-remediation runs are shown in Appendices 6 to 10, summarised in Table 7.1 and are discussed further with respect to trends, statistical significance and comparison to previously published data in Section 7.3.

Table 7.1 Investigation Numbers - Data Collection results October 2000 – November 2003 (post-remediation surveys. Runs 8-24)

(Key: DO-Dissolved Oxygen, SC-Specific Conductivity, SS– Suspended Solids, Bold type indicates comment or data set.)

Run.	Start Date	End Date	Data/ Sample Type	Location	Duration	Comments
8	16-Oct-00	23-Oct-00	Continuous	Humber Avenue	7 days	2 main rainfall peaks (< 2.5 mm hr^{-1}). <60 % DO saturation with no major changes during events (slight dip) No impact on ammonium. Specific conductivity (SC) & pH dip during events with SC returning after 2 days The results are given in full in appendix 6.1
	16-Oct-00	23-Oct-00	Continuous	Meadow Street	7 days	
	16-Oct-00	18-Oct-00	Flow	Humber Avenue	24 hours	
9	30-Oct-00	13-Nov-00	Continuous	Humber Avenue	14 days	Maximum rainfall of 4.5mm hr^{-1}. Dip in pH by max. 0.7. Fairly static for ammonium and D.O. at Humber Avenue. SC falls consistently at each event by 0.5 µS cm^{-1}. SC returns to normal level after 2 days again. The results are given in full in appendix 6.2
	30-Oct-00	13-Nov-00	Continuous	Meadow Street	14 days	
	30-Oct-00	5-Nov-00	Weekly stats rainfall	Finham STW	6 days	
	30-Oct-00	13-Nov-00	Flow	Humber Avenue	14 days	
10	23-Nov-00	7-Dec-00	Continuous	Humber Avenue	14 days	River flow constant. **Samples** BOD average 4 mg l^{-1} after initial peak at 10mg l^{-1} during early rain. Slight ammonium peak to 0.5 mg l^{-1} after 2nd rain event @4mm hr^{-1}. SS initially 200-300 becoming < 100mg l^{-1}. **No metals analysed.** Ortho P falling from 0.8 mg l^{-1} to below detection limit. Dip in pH after rain by 0.3 pH units. D.O fairly constant at 112-118% saturation. 2 day **continuous monitor** (CM) pH low at first rising by 0.3 during dry weather (coincident with daylight also). Both monitors. **Lower pH at Meadow Street by 0.5 consistently**. Slow rise in SC both sites. The results are given in full in appendix 6.3.1 and 6.3.2
	23-Nov-00	7-Dec-00	Continuous	Meadow Street	14 days	
	23-Nov-00	26-Nov-00	Weekly stats rainfall	Finham STW	4 days	
	6-Dec-00	7-Dec-00	Auto - spot sample	Humber Avenue	2 days	
	6-Dec-00	7-Dec-00	Flow	Humber Avenue	2 days	
11	19-Dec-00	21-Dec-00	Continuous	Humber Avenue	2 days	River flow reading fell after rain when monitor blocked by river debris. Low rainfall (0.5mm hr^{-}max).as 2 events. Samples at Humber Ave only. **Sample** BOD 10mg l^{-1} initially to below 5 mg l^{-1} during dry period. SS reduces after initial storm increasing to 40 mg l^{-1} average. Ortho-P not detected throughout and pH stable at 7.8- 8.0. Cd rise to <1.5µg l^{-1} falling to < 0.5. Cr initial high to 3µg l^{-1} falling to 2µg l^{-1}.and rising during 2nd storm to 3µg l^{-1}. Cu similar to Cr without 2nd peak, reaching a maximum concentration of 20µg l^{-1}. Zn initially 60-80 µg l^{-1} with slight increase after rain. Ni < detectable limit. **Continuous monitors** DO high and constant both sites. No diurnal rhythm over 2 days or impact during storms **(DO saturation lower at Meadow Street than Humber Ave).** Ammonia slightly high initially at both sites **(higher at Meadow Street than Humber Ave).** The pH showed a slight increase both sites over period **(Lower pH at Meadow Street than Humber Ave)** with 0.2 pH unit difference consistently. SC initially as trough & peaks becoming 0.5 µS cm^{-1} average **(SC slightly lower at Meadow Street than Humber Ave).** **Ammonia ND in samples but recorded by continuous monitors.** The results are given in full in appendix 6.4.1 and 6.4.2
	19-Dec-00	19-Dec-00	Continuous	Humber Avenue	19 days	
	19-Dec-00	20-Dec-00	Auto - spot sample	Humber Avenue	2 days	
	19-Dec-00	22-Dec-00	Weekly stats rainfall	Finham STW	3 days	
12	30-Jan-01	23-Feb-01	Continuous	Humber Avenue	25 days	**Continuous monitors only – full 25 days. Good correlation between flow and rainfall. Meadow St. monitor affected by debris after 4.5 mm hr^{-1} peak storm.** Ammonium < 0.55 mg l^{-1} @ Humber Ave with regular small peaks. Meadow St < 0.2 mg l^{-1} with non-storm related peak to 1.6 mg l^{-1} toward end of run. Fairly constant pH @ Humber with 7.5 average **(higher at Meadow Street than Humber Ave). Unusual result.** Meadow St average 7.7 falling to 7.2 average, which is lower than Humber Ave.. May be flow increase after rainfall event. SC trend consistent @ both sites being very slightly higher at Humber Ave. Slight peak then trough following rainfall. Temperature consistent at both sites with slight increase during day to 8°C.
	30-Jan-01	23-Feb-01	Continuous	Meadow Street	25 days	
	30-Jan-01	23-Feb-01	Flow	Humber Avenue	25 days	The results are given in full in appendix 6.5. **Key to table on sheet 7, table 7.1**

Table 7.1 Investigation Numbers - Data Collection results October 2000 – November 2003 (post-remediation surveys)

Run.	Start Date	End Date	Data/ Sample Type	Location	Duration	Comments
13	23-Feb-01	14-Mar-01	Continuous	Humber Avenue	21 days	Continuous monitors 2 days considered from 21-day investigation: 2 periods to coincide with sampling runs.
	23-Feb-01	14-Mar-01	Continuous	Meadow Street	21 days	**Both dry weather runs but river level rises twice during 9 March run (Auto 8) depicting local rain event.**
	9-Mar-01	10-Mar-01	Auto8 - spot samples	Humber Avenue	2 days	**Run 13 involved two periods of auto sampling (Auto 8 and Auto 9) on 9th and 12th March respectively:**
	12-Mar-01	13-Mar-01	Auto9 - spot samples	Humber Avenue	2 days	**Auto 8 Samples;** Ammonium not detected except during 2 peaks to < 0.8 mg l^{-1}. (During early morning and evening period) may relate to specific domestic or industrial discharge above Humber Avenue, which is only detectable in dry weather. Also slight BOD rise at 01:00 (10 to 25 mg l^{-1}) which is coincident with the second phase of the first level rise. Debris prevented collection of 20:00 hr sample, following the first river level rise which also caused slight peaks for BOD, Ammonium, and Ortho-P in samples taken immediately afterwards. TON and Total P constant at 6 mg l^{-1} and average 300 µg l^{-1} respectively. Fairly constant pHs at 7.6- 8.0 with small peak towards end of run coincident with second level rise. **All metals show a peak value, in the second last sample coincident with the second river level rise,** with Zinc showing the greatest increase to 900µg l^{-1}. Maximum values recorded for Cr, Cu, Ni, Pb & Total .P were 7, 35, 6, 50 400 µg l^{-1} respectively. **Continuous monitors** DO constant at around 80% Humber Avenue and 72-85% Meadow Street. With only slight falls corresponding increased river level @ Humber Ave and more marked deterioration at Meadow Street to 72% minimum saturation. Ammonium was a fairly constant 1.5 mg l^{-1} at Meadow Street and showed peaks at Humber Avenue before the river level demonstrated the first increase. The average level following this peak was 0.7 mg l^{-1}. Sampled ammonia does not reflect these increased levels of ammonia as a result of the hourly sample rate 'snapshot'. The pH dips slightly at both sites as a result of increased river level. The pH is generally lower at Meadow Street than Humber Ave. Temperature slightly higher (pre-culvert) at meadow Street also.
						Auto 9 samples; Small rain event (max. 0.5 mm hr^{-1}) followed by two 2 mm hr^{-1} rainfall events. BOD increased from 5 to 25 mg l^{-1}after initial rain with only slight increases at Humber Ave during following rain events. Ammonium was below detection levels except for a peak at 0.15 mg l^{-1} in one sample only following the first 2 mm hr^{-1} storm. SS increased to 500mg l^{-1} after initial rain falling and then rising steadily to <400 mg l^{-1}. Total P increased from 300 to >400µg l^{-1} after initial rain, dropping during storms and falling further post storm to original levels. The pH fell after initial rain and again during wet weather before levelling off at 8. **An initial first flush may have been sampled during this run.** **Metals all showed a similar pattern** with an initial rise following the early rain with one or two peaks following during the heavier rainfall events. Peaks for Cd, Cr, Cu, Zn, Ni, & Pb reached 0.7, 7.0, 40, 200, 6, and 60 mg l^{-1} respectively. **Continuous monitors:** Temperature fell overnight at both sites, rising next day in the dry period. **The pH at both sites showed a slight fall in pH after the initial rain,** becoming less variable after the rainstorms and increasing steadily at Meadow Street to 7.75. The pH at Meadow Street was only slightly higher than at Humber Avenue. The Ammonium level started high at Meadow Street falling to an average of 1.3 mg l^{-1}, with only insignificant rises during the storm events. Ammonium levels were again slightly higher than detected during sampling, which may indicate some stabilisation in the samples before analysis. The ammonium at Meadow Street was consistently marginally higher than at Humber Avenue. The DO at both sites dropped slightly following the initial rain but was generally unaffected by the storm events with good levels recorded (Average 90%) at both sites. Dissolved solids showed an initial peak at Meadow and 2 peaks at Humber avenue with values of 320, 375 and 350 mg l^{-1} respectively. These levels dropped during the storm periods consecutively rising slightly to around 200mg l^{-1} at both sites.
	1-Mar-01	4-Mar-01	Weekly stats rainfall	Finham STW	5 days	The results are given in full in appendices 6.6.1, 6.6.2, 6.7.1 and 6.7.2. **Key to table on sheet 7, table 7.1**

Table 7.1 Investigation Numbers - Data Collection results October 2000 – November 2003 (post-remediation surveys)

Run.	Start Date	End Date	Data/ Sample Type	Location	Duration	Comments
14	14-Mar-01	6-Apr-01	Continuous	Humber Avenue	23 days	Auto 10 samples; these results are described in Section 7.2.1.
	14-Mar-01	6-Apr-01	Continuous	Meadow Street	23 days	The results are given in full in appendix 7.
	15-Mar-01	17-Mar-01	Auto10 - spot sample	Humber Avenue	3 days	
	2-Apr-01	3-Apr-01	Auto11 - spot sample	Humber Avenue	2 days	
						Auto 11 samples; 3 rainfall events (max 1mm hr^{-1}). BOD started fairly high during early rainstorm at 14 mg l^{-1} with 2 small peaks corresponding to 2nd and 3rd event as levels fell to Av < 4 mg l^{-1}. Sampled ammonium remained below detectable levels. SS increased to 13mg l^{-1} after the initial rain and similarly showed 2 small peaks before falling to <10mg l^{-1}. TON dipped slightly on 1st and 3rd event, rising immediately afterward. Ortho-P stayed below detectable limits but total P, decreasing slowly from the start showed 2 slight increases following the 2nd and 3rd events though continuing the downward trend, with a total fall of 150 µg l^{-1} (50%). The sampled pH started low at 7.7, rising slightly and then falling after the 3rd event before slowly rising during the early morning to 7.9. The metals started with a slight increase during the initial rain and a second rise after the 3rd event, with the exception of Cd which showed an initial high value falling with one peak only, after the 3rd event, and Ni which started at just over 6 µg l^{-1} and then fell below detectable levels for the remainder of the sampling period. Cl showed the same trends as the heavy metals but to a lesser degree. **Continuous monitors;** after an initial rise at both sites, DO fell slightly at the start of the 2nd event at Meadow St and slightly later at Humber Ave. The 3rd event only had a slight effect and average levels of 73% (Meadow St) and 79% (Humber Avenue) persisted before rising to 84 % and 86% respectively. Ammonium levels peaked early in the 2nd and 3rd events at Meadow St (maximum 1.1mg l^{-1}) with slight falls between, whilst at Humber Ave the level was considerably lower with only a slight increase during the 1st and 3rd events (maximum 0.3 mg l^{-1}). The pH at Meadow Street dropped more rapidly after the initial rain than at Humber Avenue but remained generally higher than the downstream site. Both sites showed a slight fall in pH following the 2nd and 3rd rainfall events. The trends at both sites were identical with a gradual rise to 7.8 and 7.7 respectively. The dissolved solids at Meadow Street started high during the wet period and then dropped rapidly with only slight variation during the 2nd and 3rd events. At Humber Ave the rain events caused an increase of 0.01 g l^{-1} with a continued increase to 0.23 g l^{-1} toward the end of the run. The levels were consistently higher than those recorded at Meadow Street. The temperature measurement at both sites showed a gradual fall over the hours of darkness with similar levels at both sites.
	14-Mar-01	18-Mar-01	Weekly stats rainfall	Finham STW	5 days	The results are given in full in appendix 6.8.1 and 6.8.2. **Key to table on sheet 7, table 7.1**

Table 7.1 Investigation Numbers - Data Collection results October 2000 – November 2003 (post-remediation surveys)

CONTINUOUS MONITOR RUNS ONLY (longer periods of monitoring presented)						
Run.	Start Date	End Date	Data/ Sample Type	Location	Duration	Comments
15	6-Apr-01	30-Apr-01	Continuous C4	Humber Avenue	21 days	3 large groups of storms, with over 14 recorded rainfall periods. Results highly consistent with recorded depth. DO demonstrated a diminished diurnal variation during initial rain period (max.2.5mm hr^{-1}) gradually increasing as the frequency of the rain events reduced before again being diminished following an intense rain event over 4 hours. (max. 2.5mm hr^{-1}) The data recorded at Meadow Street was almost identical to that recorded at Humber Ave with an average of 90% saturation at both sites. Ammonium levels at Meadow Street remained fairly constant with regular small peaks to <3 mg l^{-1} rather than as a result of the initial rainfall period but during the second large storm event the ammonium levels rose to 10mg l^{-1}. At Humber Avenue there was no such rise indicating the possibility that debris on the Meadow Street monitor was causing aberrations of the results. At Humber Ave a maximum of 1.4 mg l^{-1} with unexplained diurnal peaks recorded . These peaks though smaller, were also identified at Meadow Street. **As yet these peaks are unexplained, but may be due to algal populations.** The level of ammonium at meadow Street was generally higher than that at Humber Ave. The dissolved solids at both sites started at 0.2g l^{-1} with slight dips consistent with individual rain events followed by subsequent return to slightly elevated levels. The second major event resulted in a dip of over 0.2 g l^{-1} at both sites but the peak at Humber Ave was 0.8 compared to 0.4 g l^{-1} at Meadow Street. The average was slightly higher at Humber Avenue. Continuous pH and temperature at both sites was very consistent rising during the day and falling through the night in line with the diurnal variations outlined above. The fall in pH at Humber Avenue following the second major storm was less marked than at Meadow Street. The results are given in full in appendix 6.9.
	6-Apr-01	30-Apr-01	Continuous C4	Meadow Street	21 days	
	9-Apr-01	30-Apr-01	Flow	Humber Avenue	21 days	
16	30-Apr-01	15-May-01	Continuous C5	Humber Avenue	24 days	Depth measurements only taken for second half of run. 3 major increases in depth towards end of run. Short rainfall event earlier in run. **DO showed good diurnal rhythm** at both sites with only minimal disruption during first rainfall event. The 2nd monitored depth increase coincided with total disruption of Diurnal variation at Humber Ave and a drop to 0% saturation (possibly due to blockage by debris) at meadow Street. Humber Avenue did not recover for the rest of the monitored period and Meadow St recorded another drop to 0% for the final event. In between events at meadow Street diurnal rhythm returned. Other than these reductions, DO did not fall below 60% at Meadow Street and 55% at Humber Ave. **Good correlation between results, high level of DO maintained and disruption evident as a result of storm flows.** Ammonium levels at Meadow Street reflected the rainfall events with peaks to a maximum of 1.1 mg l^{-1}. **At Humber Avenue these peaks were added to by non-storm related events** (max 1.5 mg l^{-1}), which may have been due to local rainfall events or unknown discharge. The final major rainfall event (max. 11mm hr^{-1}) impacted heavily on Meadow Street but not to the same extent at Humber Ave. The mean concentration at Humber Ave was slightly higher however, than at Meadow Street. **The pH showed a strong diurnal rhythm,** which was again disrupted by the 2nd depth increase. The diurnal rhythm recovered more quickly than the DO disruption but was again more exaggerated at Meadow Street. Total Dissolved Solids at Meadow St fell sharply at both sites following the 2nd rise in measured depth but **there was an additional reduction in TDS** in line with the additional ammonium peak identified above. The temperature was similarly affected with a short peak to 18°C (from 12°C). Only one peak (to 18°C) was recorded at Meadow St, in line with the 3rd river depth rise. The diurnal rhythm for temperature was more marked at Meadow St., as would perhaps be expected in an open watercourse in late Spring.
	30-Apr-01	15-May-01	Continuous C5	Meadow Street	24 days	
	07-May-01	15-May-01	Flow	Humber Avenue	21 days	The results are given in full in appendix 6.10. **Key to table on sheet 7, table 7.1**

Table 7.1 Investigation Numbers - Data Collection results October 2000 – November 2003 (post-remediation surveys)

Run.	Start Date	End Date	Data/ Sample Type	Location	Duration	Comments
17	17-May-01	06-Jun-01	Continuous C6	Humber Avenue	21 days	One 3 mm hr^{-1} rainfall event at beginning of run, plus 3 later small events (2 @ 1mm hr^{-1}). River depth doubled from 20 cm to 40cm. **The DO diurnal rhythm was markedly disrupted at both sites by the initial rainfall event without any marked deterioration in % saturation,** and slowly recovered before being disrupted again by the second, more minor event. Disruption from the final storm event disrupted only the Humber Ave site to a significant degree. Both sites were consistent with each other but the DO at Humber Avenue was generally lower than at the Meadow St site, with minimum values of <40% saturation. The ammonium monitor at Meadow St appeared to malfunction following the initial storm event **but at Humber Ave the resultant ammonium peaks for each storm event did not exceed 0.2 mg l^{-1}.** The recorded pH again showed diurnal variation over the period of 21 days and the disruption to this pattern was similar to that of the DO results discussed above. The pH dropped during the rainfall events and the Humber Ave site was generally more acidic than Meadow Street (0.2 difference in max. levels). TDS at Meadow St and Humber Ave fell sharply during the initial rainfall event, but only the Humber Ave site showed a slight dip during the 2nd rainfall event. Both sites showed a dip during the 3rd event (max variation 0..2 g l^{-1}) but the fall was more rapid at Humber Ave as was the case with pH. This was possibly due to the impervious nature of the local environment. The level of TDS at Humber Ave was slightly higher at Humber Ave (0.05g l^{-1} difference). **Temperature at meadow St again showed a stronger diurnal rhythm** than at Humber Ave though an average of around 14°C was recorded at both sites. **The rainfall diminished the diurnal variation** at both sites during each rainfall event, without causing deterioration.
	17-May-01	06-Jun-01	Continuous C6	Meadow Street	21 days	
	17-May-01	06-Jun-01	Flow	Humber Avenue	21 days	The results are given in full in appendix 6.11. **Key to table on sheet 7, table 7.1**
18	06-Jun-01	29-Jun-01	Continuous C7	Humber Avenue	23 days	The depth monitor failed due to collected debris after the sing le main rainstorm. The rainfall was intense reaching a peak of 7mm hr^{-1} and lasting for 2 days. **The DO at both sites showed a good diurnal rhythm, which was reduced significantly at both sites thought the average level of around 80% saturation was maintained at both sites.** The degree of variation at the Meadow St site was lessened for the remainder of the run. **The Humber Ave site returned to its former diurnal rhythm.** The continuous ammonium at Meadow St show a less pronounced increase during the storm event than Humber Ave, with peaks of 0.5 & 0.7 mg l^{-1} respectively. Both sites showed a later peak to a maximum of 0.9 mg l^{-1} at Meadow St and 1.2mg l^{-1} at Humber Avenue, which does not seem to correlate with Finham rainfall records. Unfortunately the failure of the level device could not confirm whether a local rainfall event was responsible. **Again the pH diurnal rhythm was disrupted by the storm** with only a minor decrease in the average pH following the event (<0.5 difference). The diurnal rhythm returned to its former pattern at only the Humber Avenue site, as with the DO observations above. TDS dipped markedly as a result of the storm event at both sites and levels were generally higher at Humber Ave (Av 0.3- 0.4 g l^{-1}) than at Meadow St (0.275- 0.325g l^{-1}). Temperature showed a greater degree of diurnal variation at the open Meadow St site and the rhythm was disrupted at both sites by the storm event.
	06-Jun-01	29-Jun-01	Continuous C7	Meadow Street	23 days	
	06-Jun-01	16-Jun-01	Flow	Humber Avenue	23 days	The results are given in full in appendix 6.12. **Key to table on sheet 7, table 7.1**

Table 7.1 Investigation Numbers - Data Collection results October 2000 – November 2003 (post-remediation surveys)

Run.	Start Date	End Date	Data/ Sample Type	Location	Duration	Comments
19	29-Jun-01	27-Jul-01	Continuous C8	Humber Avenue	29 days	This run started during a storm event with max 5mm hr^{-1}. There were subsequently several storm events, which resulted in river depth increases on a further 5 distinct occasions, **the greatest of which increased the depth of the river at Humber Ave 5 fold. DO at Meadow St fell dramatically (to <20% saturation)** following the initial heavy storm but then very quickly returned to normal diurnal rhythm. Humber Ave showed no such deterioration with only minimal disruption of diurnal patterns. During the second storm (max. 4mm hr^{-1}) the diurnal rhythm at both sites was interrupted briefly and at Humber Ave there was a slight deterioration in quality to a minimum of <20%saturation before improving back to normal levels during the 5th storm (max. 7mm hr^{-1}). Diurnal rhythm at this point was disrupted at both sites and a return to regular peaks and troughs over 5 days, although the average DO at Meadow St reduced over this period to give minimum values of <10mg l^{-1}. It would appear that this intense rain had caused operation of the high level overflow at Albany Rd , although this effect was not demonstrated at Humber Ave until after the second storm. **Debris may have been responsible for the initial low DO results though these were repeated at both sites during the run several times**. The Meadow St monitor continuously recorded ammonium levels at 1.1 mg l^{-1} with one result at 1.3 mg l^{-1} following the large 5th storm. The Humber Avenue site also recorded regular diurnal peaks but to a lower (0.4 mg l^{-1}) level with a max value of 0.5mg l^{-1}. Following the final storm levels at both sites returned to <0.4 mg l^{-1}. The pH at both sites again showed a decrease during storm conditions with disruption of diurnal patterns during each storm. The severity of the storm seemed a factor in how much disruption and reduction in pH occurred at both sites. **The pH fell over 0.5 pH units at Meadow St. following the second storm**. Diurnal rhythm quickly returned to normal (within 24 hours). TDS fell with each storm event, returning to normal levels (0.35 g l^{-1}) after 2 to 8 days. TDS levels at Humber Ave were consistently higher by approximately 0.05g l^{-1}.Temperature readings at the open Meadow St. site were again subject to considerable diurnal variation compared to the Humber Ave location. The storm events had no major impact on the temperature readings recorded and average temperatures were approximately the same at both sites.
	29-Jun-01	27-Jul-01	Continuous C8	Meadow Street	29 days	
	02-Jul-01	27-Jul-01	Flow	Humber Avenue	25 days	The results are given in full in appendix 6.13. **Key to table on sheet 7, table 7.1**
20	27-Jul-01	18-Aug-01	Continuous C9	Humber Avenue	23 days	The first 50% of the run showed no increase in river depth and there were more than 8 peaks in depth in the second half of the investigation. The first and largest storm event (which resulted in a doubling of the depth at Humber Ave) caused a disruption of the DO diurnal rhythm although again no decrease in minimum levels was detected at either site. With the repeated storm events over the next 10 days, the diurnal pattern did not recover fully. Minimum levels recorded at Meadow St were approximately 50-60% saturation and at Humber Ave it was lower at 30-40% saturation. **The decrease in maximum % saturation from 150%+ to less than 100% denotes a major impact on algal activity/ presence. DO levels were consistently higher at Meadow St.** Ammonium levels were insignificant at both sites with peaks to 0.1mg l^{-1} in line with storm events, particularly at Humber Ave. The pH showed a strong diurnal pattern, which was disrupted during and following the rainstorm events. The pH trends at both sites were very consistent and values at Humber Ave were generally higher than Meadow St. (which is contrary to previous runs) with maximum levels at 8.7pH units. **At Meadow St. the pH dropped by up to 0.8 pH units following the 2 major storms.** TDS was again reduced markedly during the storm events and each small rain event had the same impact during this investigation with a high level of consistency between the 2 sites. TDS at Humber Ave was slightly higher at 350 g l^{-1} (difference of 0.5-0.1 g l^{-1}) **. Temperatures at both sites were similar though more diurnal variation was recorded at Meadow St.** The storms had no impact on temperatures recorded at both sites.
	27-Jul-01	18-Aug-01	Continuous C9	Meadow Street	23 days	
	27-Jul-01	18-Aug-01	Flow	Humber Avenue	23 days	The results are given in full in appendix 6.14. **Key to table on sheet 7, table 7.1**

Table 7.1 Investigation Numbers - Data Collection results October 2000 – November 2003 (post-remediation surveys)

Run.	Start Date	End Date	Data/ Sample Type	Location	Duration	Comments
21	17-Aug-01	29-Aug-01	Continuous C10	Humber Avenue	12 days	This investigation had one period of extended storms in the first week. The diurnal rhythm for DO and pH were disrupted at both sites by the early storm period and the monitor at Meadow Street developed a fault in the DO and ammonium probes as a result of debris. The probe started working again for DO after 2.5 days. Minimum DO levels were generally higher at Meadow St. although maximum levels were higher at Humber Ave. Ammonium levels were again reduced during this investigation with maximum values of 0.3mg l^{-1}. Only 1 peak (0.2mg l^{-1}) was recorded for ammonium at Meadow St. The pH at both sites was affected in that a drop in pH (0.6 pH units) was evident and the diurnal rhythm was broken for 24 hours at Meadow St. and for four days at Humber Avenue. TDS dropped dramatically at both sites (0.35g l^{-1} to 0.05g l^{-1} Humber Ave and 0.275g l^{-1} to 0.06g l^{-1} at Meadow Street. Correlation between the 2 sites was very good and Meadow St was consistently lower in TDS throughout the run. Temperature showed greater diurnal variation at Meadow St. than at Humber Ave., with lower temperatures recorded as minima. The results are given in full in appendix 6.15.
	17-Aug-01	29-Aug-01	Continuous C10	Meadow Street	12 days	
	17-Aug-01	29-Aug-01	Flow	Humber Avenue	12 days	
22	29-Aug-01	15-Oct-01	Continuous C11	Humber Avenue	17 days	Multiple storms throughout the run. Depth monitor installed 1 day later. DO showed steady diurnal rhythm with slight decreases (to 50% saturation) at Meadow St. initially but with substantial fall to 0% during large final storm (depth increase 6 fold) returning to normal diurnal rhythm without deterioration. At Humber Ave the diurnal variation was greater (40-90%) but at a generally lower level. Storm events interfered with diurnal rhythm and the intense period of depth increase in the last quarter of the run resulted in a drop to zero % for a period of up to 6 hours. During the final storm DO dropped to 10% saturation. Diurnal rhythm returned quickly at both sites. Ammonium at Meadow St did not increase markedly until the last quarter of the investigation. Levels of 1mg l^{-1}were achieved. At Humber Ave an initial rise in ammonium to 1.0 mg l^{-1} was not repeated. A good diurnal rhythm was recorded at both sites and a decrease in minimum pH was identified for each increase in river depth. The pH at Humber Ave was more variable. At both sites TDS fell sharply during each storm event, returning to an average of 3g l^{-1} at Meadow St and 0.35g l^{-1} at Humber Ave. within 5 hours. Temperature at both sites was not affected by the storms. The readings for Humber Ave were consistently slightly higher than at Meadow St. with less diurnal variation.
	29-Aug-01	15-Oct-01	Continuous C11	Meadow Street	17 days	
	30-Aug-01	15-Oct-01	Flow	Humber Avenue	16 days	The results are given in full in appendix 6.16. **Key to table on sheet 7, table 7.1**

Table 7.1 Investigation Numbers - Data Collection results October 2000 – November 2003 (post-remediation surveys)

Later Post –remedial runs 2003						
Run	Start Date	End Date	Data/ Sample Type	Location	Duration	Comments
23	30-Sep-03	----	River Level/ Flow US	Kingsbury Avenue	1 day	Dry weather period used for investigation with continuous monitor and auto-sampler at both sites. The results of this investigation are shown in appendix 8, and discussed in Section 7.2.2.
	30-Sep-03	----	River Level/ Flow DS	Whitley	1 day	
	30-Sep-03	----	Rainfall	Finham	1 day	
	30-Sep-03	----	Auto - spot sample	Humber Avenue	1 day	
	30-Sep-03	----	Auto - spot sample	Meadow Street	1 day	
	30-Sep-03	----	Continuous	Humber Avenue	1 day	
	30-Sep-03	----	Continuous	Meadow Street	1 day	
24	25-Nov-03	26-Nov-03	River Level/ Flow US	Kingsbury Avenue	2 days	Storm events investigated with continuous monitor and auto-sampler over 2 days at both sites. The results of this investigation are shown in appendix 9 and appendix 10, and discussed in Section 7.2.3.
	25-Nov-03	26-Nov-03	River Level/ Flow DS	Whitley	2 days	
	25-Nov-03	26-Nov-03	Rainfall	Finham	2 days	
	25-Nov-03	26-Nov-03	Auto - spot sample	Humber Avenue	2 days	
	25-Nov-03	26-Nov-03	Auto - spot sample	Meadow Street	2 days	
	25-Nov-03	26-Nov-03	Continuous	Humber Avenue	2 days	
	25-Nov-03	26-Nov-03	Continuous	Meadow Street	2 days	
	KEY:		Auto spot sample			Flow
			Rainfall (Weekly Stats)			Continuous monitor

7.1 Investigation of post-remedial conditions in the River Sherbourne culvert

Where investigative runs included the use of the ISCO auto sampler (Plate 4.3), analysis for heavy metals and sanitary determinands, including ammonium and BOD were carried out. The heavy metal concentrations were measured to determine which pollutants remained after the initial purge of organic sources, such as the removal of a number of combined sewer overflows and illegal drainage misconnections (objectives 3 and 5, Section 1.5). This enabled an assessment of the problems that may need to be addressed in future catchment management decisions, on the use, maintenance and improvement of the urban areas of the River Sowe catchment. Heavy metal data is not currently determined by the Environment Agency for the River Sherbourne catchment, as there are no consented metal-bearing discharges to the watercourse, and no requirement to achieve metal limits under current legislation. However, if the existing length of the River Avon (Figure 3.1) designated as cyprinid fishery, is extended upstream to include the River Sowe below the confluence with the River Sherbourne, the heavy metal concentrations discharged, in urban runoff, from the River Sherbourne catchment, may be important. Heavy metal concentration in urban runoff will also be an important component for measuring water quality under future water quality legislation, such as the Water Framework Directive (200/60/EC)(Sections 2.6 and 3.11).

The BOD was measured to establish whether conventional water quality guidelines were being breached during storm events, and whether the concentrations recorded were greater than those identified by routine General Quality Assessment (GQA) monitoring, as identified in Section 3.3. The values obtained would also identify whether Fundamental Intermittent Standards (Section 2.5.1), as proposed by the UPM methodology (FR/CL 0002. FWR, 1994) would be met (see objective 1, Section 1.5),

and whether this had any bearing on the potential future uses relating to amenity, recreation or abstraction of the River Sherbourne, should water quality improve.

Hourly spot samples taken for total ammonia (ammonium) determination (ISCO auto-sampler, Figure 4.11) assisted in considering these objectives, but also acted as a comparison with continuously monitored results to determine the accuracy of obtained data, and identify pollutant concentrations below detectable levels for laboratory analysis. These factors, along with a consideration of the benefits (or otherwise), of increased data collection, achieved by continuous monitoring over hourly automated or monthly manual sampling, are discussed in Chapter 8. The automated sampling also allowed detection of other pollutants, such as SS and phosphate, which were not measured by the continuous monitors.

7.2 Featured investigation results-for post-remedial phase (Phase 3)

Three events will be discussed in detail in this section as follows:

1. Continuous monitor results obtained at Meadow Street and Humber Road, and auto sample results from Humber Avenue, for a storm event which took place on 15 – 17 March 2001
2. A dry weather period over 12 hours in September 2003, using continuous monitors at Meadow Street and Humber Avenue, with auto sample results at both sites.
3. A storm event on 25 – 26 November 2003, using continuous monitors at Meadow Street and Humber Avenue, with auto sample results from both sites.

The three featured events were chosen to represent post-remedial investigations which would identify pollution levels in the River Sherbourne catchment during both dry

weather and rainfall events following remediation of the Albany Road combined sewer overflow, as well as removal (or redirection to the foul sewer), of identified misconnections and illegal discharges in the culverted watercourses draining to the watercourse, during Phase 2. The March 2001 investigation used continuous monitors upstream and downstream of the city, with an automated sampler deployed at the Humber Avenue site during a single rainfall event. The 2003 runs used automated sampling at Meadow Street upstream of the city and Humber Avenue downstream of the city, in conjunction with continuous monitors at both sites. The results were compared to pre-remedial and earlier (March 2001) post-remedial data (Table 7.16), to determine any change to the impact of the city centre urban drainage, on the River Sherbourne. Discussion on whether the data recorded met the objectives of this research is made in Chapter 8.

7.2.1 Storm event 15 – 17 March 2001.

The results considered in this section relate to the investigation of a storm event between 15 and 17 March 2001, recorded at Meadow Street and Humber Avenue in Coventry, using local rainfall measured at Coventry STW (Finham), and measured flow from Humber Avenue, as discussed in Section 4.5. Water quality data were obtained using an ISCO 6700 automatic sampler (Figures 4.11 and 4.12) collecting hourly composites, at 15-minute sampling intervals, at the Humber Avenue site only (Figure 4.18). YSI 6920 continuous water quality monitors (Figure 4.2 to 4.4) were used at Meadow Street and Humber Avenue, to obtain continuous water quality data for upstream and downstream of the culverted section of the River Sherbourne. The equipment was installed as shown in Figures 4.16 to 4.19.

i) Flow data and rainfall

Figure 7.1 and 7.2 show the results from the RMI Flowrat monitor over the period of 15 March 2001, at 14: 00 hours to 14: 45 hours on 17 March 2001. The depth was monitored only at Humber Avenue, as only one monitor was available. The depth (Figure 7.1) and velocity (not graphically presented here) as measured, were used to calculate the flow rate (Figure 7.2) in cumecs ($m^3 s^{-1}$) using the known cross-sectional area and pre-investigation calibration.

The depth of the River Sherbourne at Humber Avenue was 20.16 cm at the beginning of the investigation period rising slightly to 25.6cm following light rainfall in the first 24-hour period of the study. The flow rate increased from $0.19m^3 s^{-1}$ to $0.29m^3 s^{-1}$, accordingly. Rainfall data collected at Coventry Sewage Treatment Works showed sporadic precipitation over the same period as shown in Figure 7.3). A dry period for 15 hours from 08:00 on 16 March to 23:00 on 17 March was followed by a large storm, lasting over 10 hours, with rainfall intensity rising to 2.5 mm per hour. Depth in the watercourse increased to a maximum of 48.93 cm at 03:15 hours on the 17 March, with resultant velocity and flow rate at 1.17 m s^{-1} and $0.54m^3 s^{-1}$ respectively. Rainfall and flow rate showed a secondary but smaller peak 3 hours after the first, before river depth recovered to previous levels.

Figure 7.1 Depth at Humber Avenue 15-17 March 2001

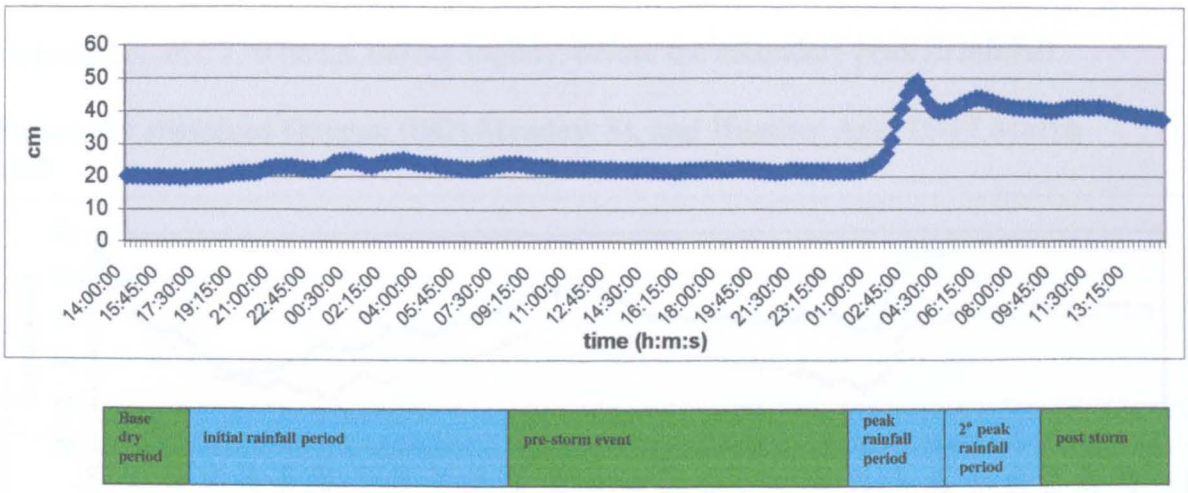


Figure 7.2 Flow at Humber Avenue 15-17 March 2001

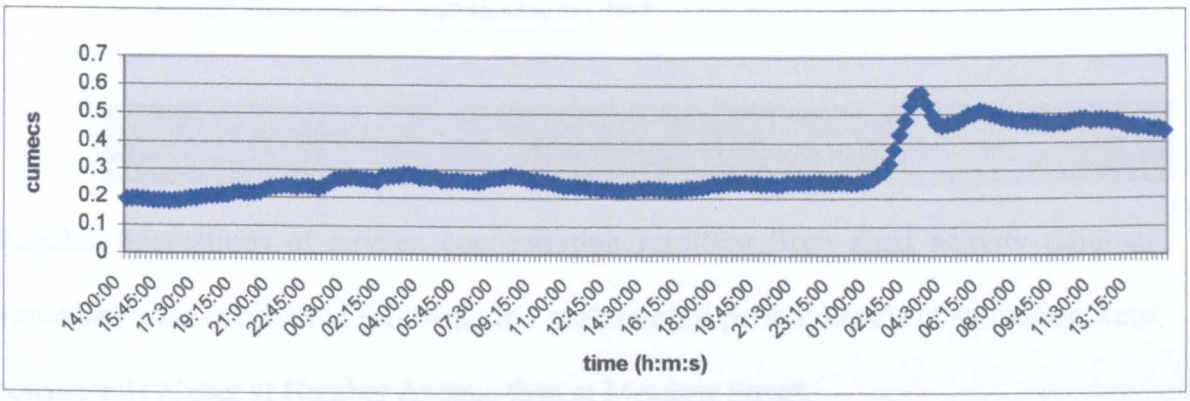
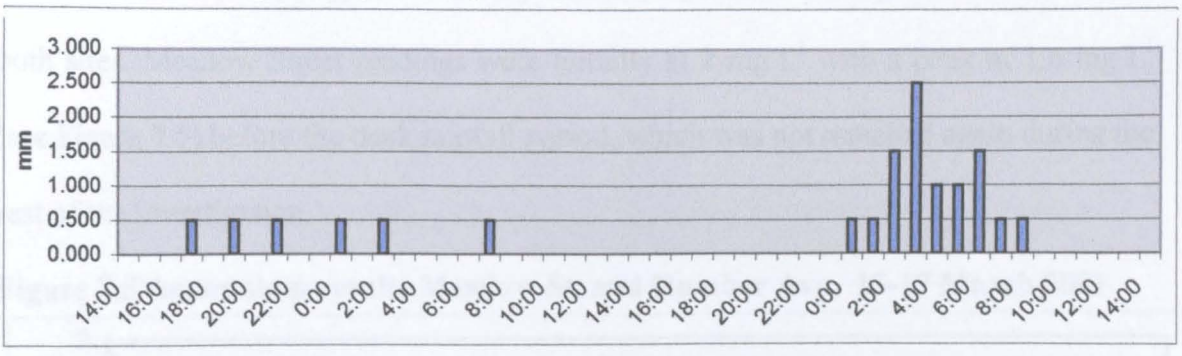


Figure 7.3 Coventry area (Finham) rainfall 15-17 March 2001

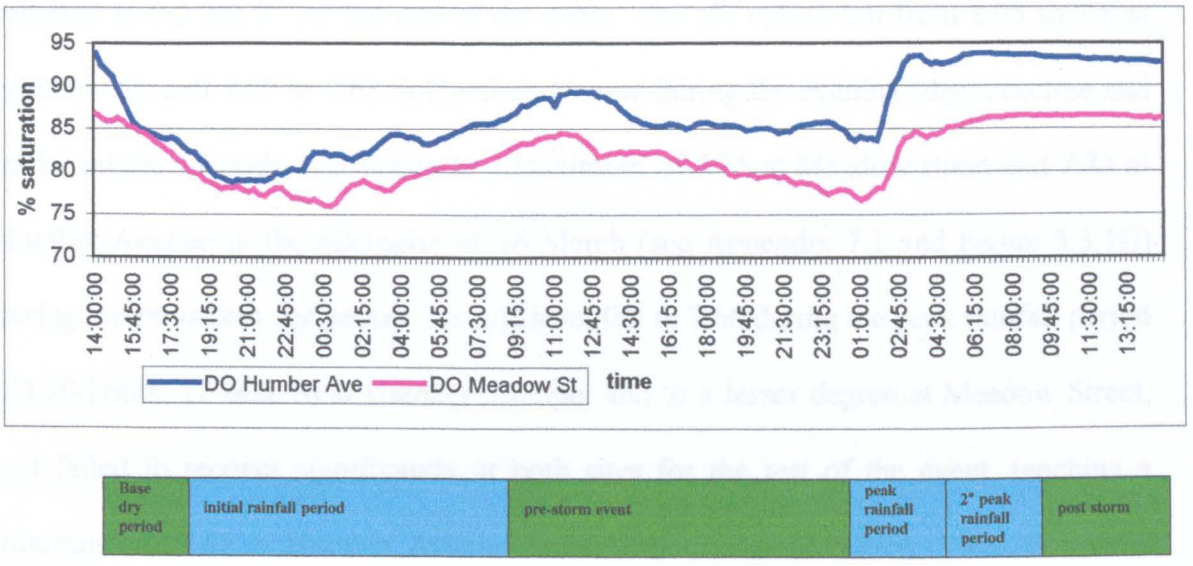


ii) Continuous monitor results

The Dissolved Oxygen percentage saturation at both sites (see Figure 7.4) was initially 87% and 93.8% respectively. DO fell to 75% and 78.7% as darkness fell, and the rain started to fall. During the initial rainfall period the Dissolved Oxygen saturation gradually rose, before falling back to around 77% at Meadow Street, and 85% at

Humber Avenue. The peak period resulted in maximum saturations of 86% and 93.4% respectively, at 03:30 hours, falling slightly, before the secondary peak in rainfall.

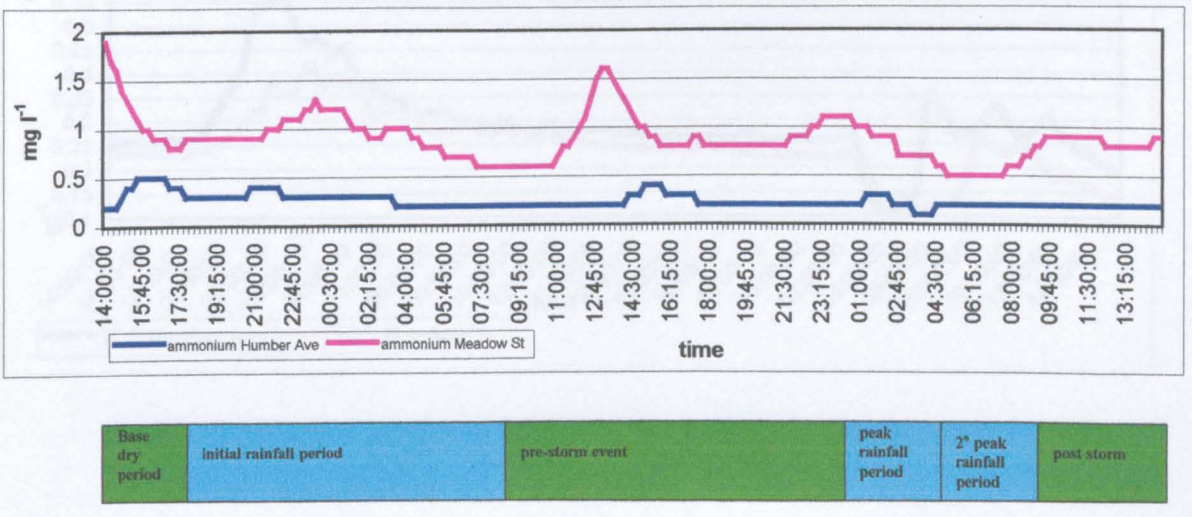
Figure 7.4 Dissolved Oxygen (DO) Meadow St. and Humber Ave. 15-17 March 2001



Regular fluctuations of oxygen concentration resulting from algal activity (Diurnal variation) were interrupted following the peak rainfall period. Levels of saturation were consistently higher at Humber Avenue than at Meadow Street.

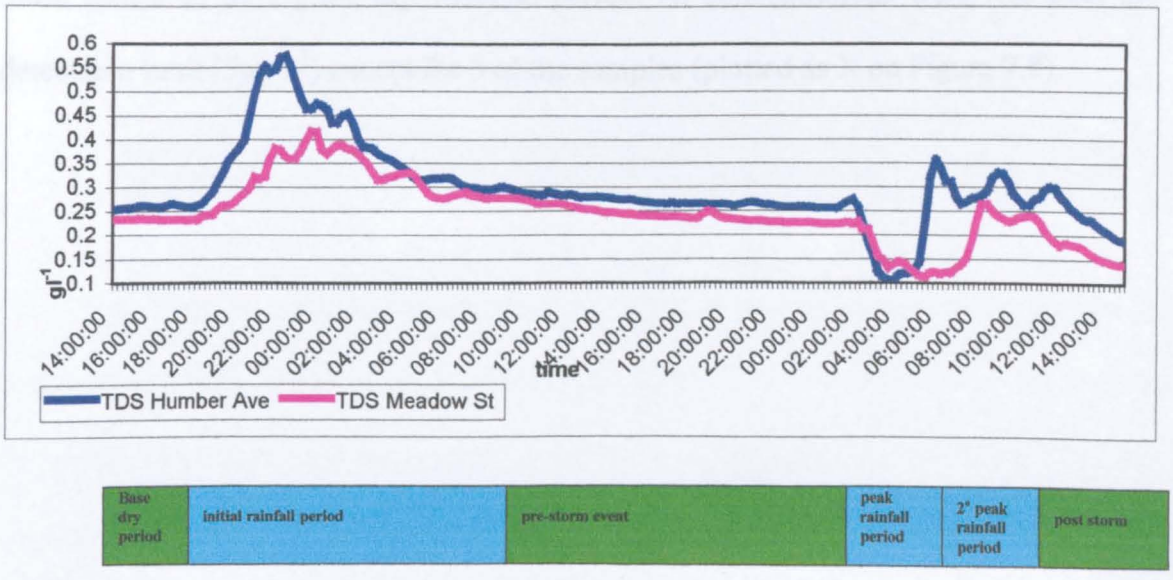
Total ammonia ($NH_4^+(N)$) showed only minor fluctuations during the storm event at both sites. Meadow Street readings were initially at 2 mg l^{-1} with a peak of 1.6 mg l^{-1} (see Figure 7.5) before the peak rainfall period, which was not matched again during the rest of the investigation.

Figure 7.5 Ammonium results Meadow St. and Humber Ave. 15-17 March 2001



At Humber Avenue maximum values of 0.5 mg l^{-1} were observed in the dry baseline period followed by a return to 0.2 mg l^{-1} during the initial rainfall period with a delayed increase to 0.4 mg l^{-1} preceding a peak rainfall period value of 0.3 mg l^{-1}. The level returned to 0.2 mg l^{-1} for the rest of the event. The pH values fell from 8.05 to 7.8 at Meadow St. and 7.99 to 7.68 at Humber Avenue during the evening (dry) baseline and initial rainfall periods, recovering to a maximum of 7.95 at Meadow street and 7.83 at Humber Avenue in the afternoon of 16 March (see Appendix 7.1 and Figure 5.3.1f)) during the pre-storm dry period. The pH level fell to 7.66 during the peak rainfall period (03:00 hours, 17 March) at Humber Avenue, and to a lesser degree at Meadow Street, and failed to recover significantly at both sites for the rest of the event, reaching a minimum of 7.65 at Humber Avenue at 08:30 hours on 17 March. Total Dissolved Solids were calculated by the monitor software using conductivity data. Before the rainfall event in the dry baseline period, TDS (Figure 7.6) rose to 0.425 g l^{-1} at Meadow Street and 0.575 g l^{-1} at Humber Avenue. The TDS concentration fell at both sites as the flow rate increased during the peak rainfall event rising briefly before reducing slowly to 0.19 g l^{-1} and 0.2 g l^{-1} respectively, at the end of the monitoring period. TDS was consistently higher at Humber Avenue, except during the peak rainfall period.

Figure 7.6 Continuous TDS Meadow St. and Humber Ave. 15-17 March 2001



Temperature readings at both sites were fairly constant maintaining an average of 7.5 °C (see Appendix 7.1). During the peak rainfall period, the temperature at Humber Avenue fell more sharply than at Meadow Street, to a minimum of 4.36 °C at 06:15 on the 17 March. The temperature increased slowly at both sites following the secondary peak rainfall period. The temperature at Meadow Street was slightly lower than at the Humber Avenue site, which may reflect the wider nature of the river channel above the sampling point or the impact of warmer point source contamination from the culverted watercourses in the centre of the city.

iii) Auto Sampling results - Heavy metals

All samples were analysed for total metals, which included, Zn, Cu, Ni, Pb, Cd and Cr (Figures 7.7 and 7.8). During the pre-storm period, debris blocked the auto-sampler intake and one sample was missed. All of the heavy metals showed a strikingly similar pattern during the storm event, with a minor peak in the early hours of the initial rainfall period, followed by a general reduction in concentration until the peak rainfall period. During the secondary peak rainfall period a second large peak, followed by a lesser peak of concentration, was displayed for each metal analysed. Following the storm all heavy metal concentrations remained at levels which were two or three times higher that those measured during the dry baseline period. Ni concentrations were less than the detectable limit (5$\mu g\ l^{-1}$) except for 6 of the samples (plotted as X on Figure 7.8).

Figure 7.7 Auto-sample results – Cu and Zn Humber Ave 15-17 March 2001

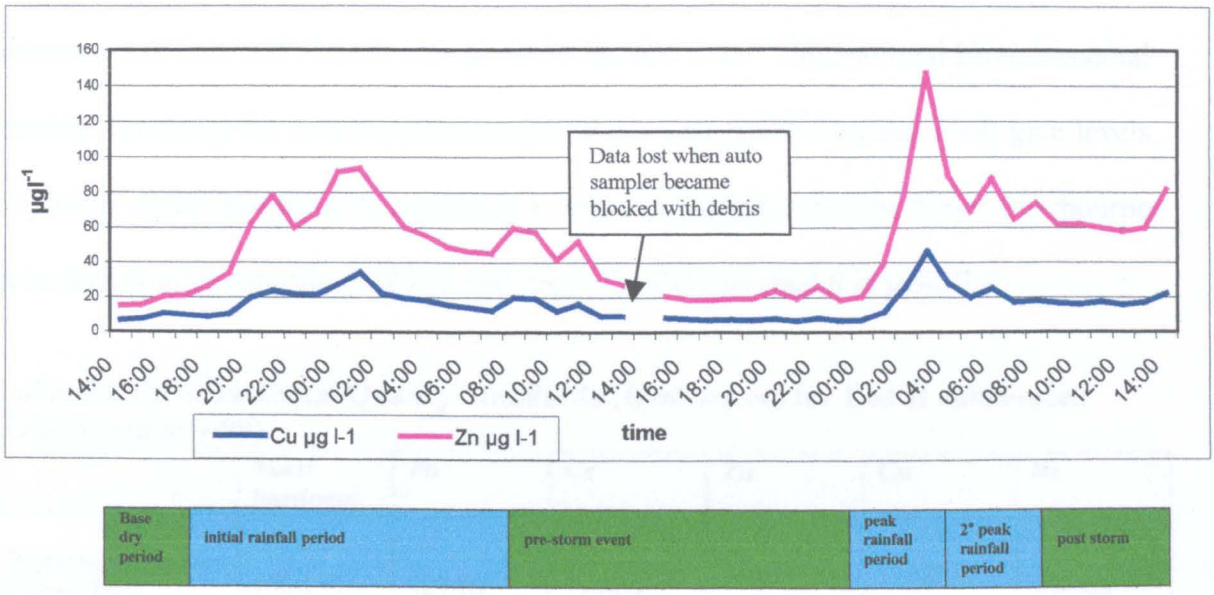
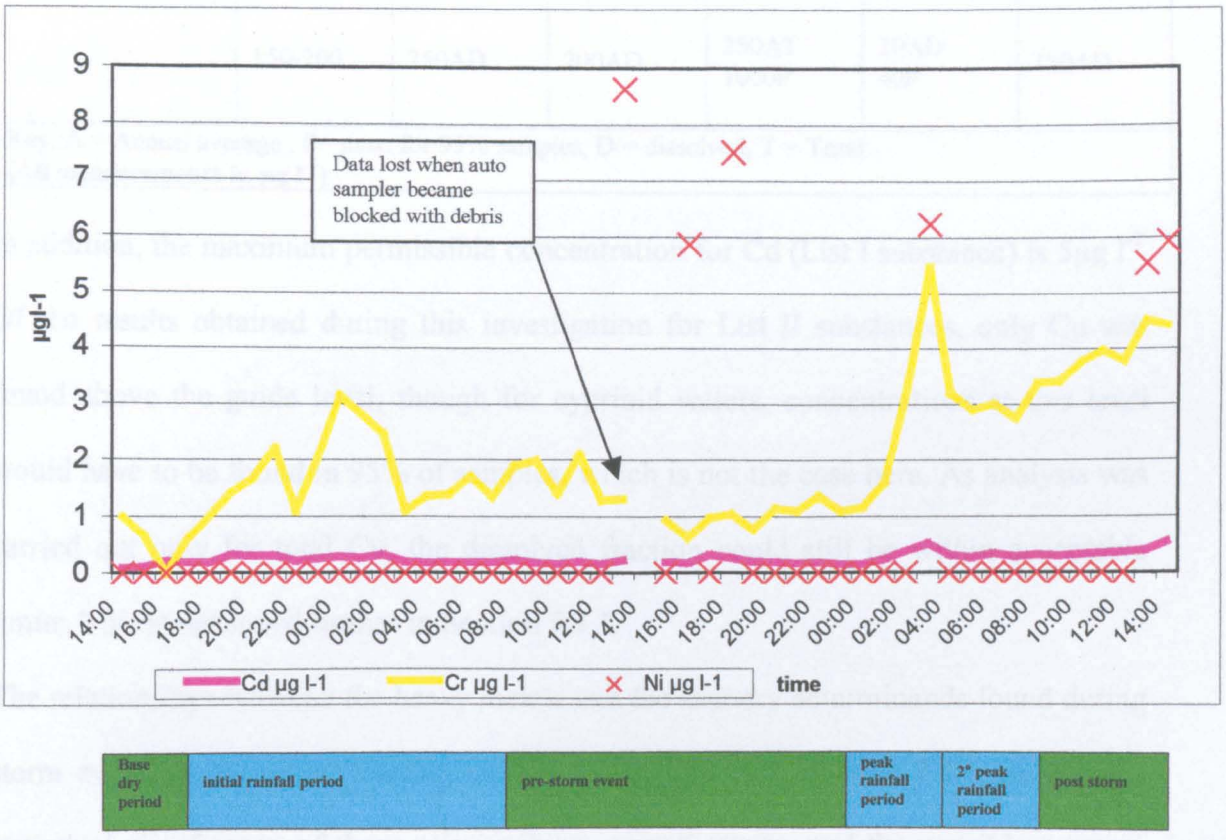


Figure 7.8 Auto-sample results – Ni, Cd and Cr Humber Ave 15-17 March 2001



The River Sherbourne is not a salmonid or cyprinid watercourse, and the standards required by the EC Freshwater Fish Directive (78/659/EEC) and associated regulations do not therefore apply, but the mandatory (95%), and strictest, value of 0.2 mg l^{-1} Zn for salmonid fisheries was not exceeded. The maximum concentration for Cu of 46µg l^{-1}

recorded during this storm event was greater than the guideline concentrations for both salmonid and cyprinid fisheries, as given in Section 2.4.4. The National Environmental Quality Standards for List II substances for freshwater (DOE Circular 7/89) give levels for heavy metal compliance, assuming a range of hardness for the River Sherbourne (based on routine sampling) of 100-180 mg l^{-1} Ca CO_3, as shown in table 7.2:

Table 7.2 Environmental Quality Standards (freshwater) for List II substances (DOE Circular 7/89)

	Total hardness	**Pb**	**Cr**	**Zn**	**Cu**	**Ni**
Protection of other aquatic life (e.g. cyprinid fish)	100-150	125AD	175AD	250AT 1000P	10AD 40P	150AD
	150-200	250AD	200AD	250AT 1000P	10AD 40P	150AD
Key: A = Annual average , P= max. for 95% samples, D = dissolved, T = Total **(All measurements in µg l^{-1})**						

In addition, the maximum permissible concentration for Cd (List I substance) is 5µg l^{-1}. Of the results obtained during this investigation for List II substances, only Cu was found above the guide level, though for cyprinid waters, concentrations at this level would have to be found in 95% of samples, which is not the case here. As analysis was carried out only for total Cu, the dissolved fraction could still be within acceptable limits. This is discussed further in Section 7.4.1.

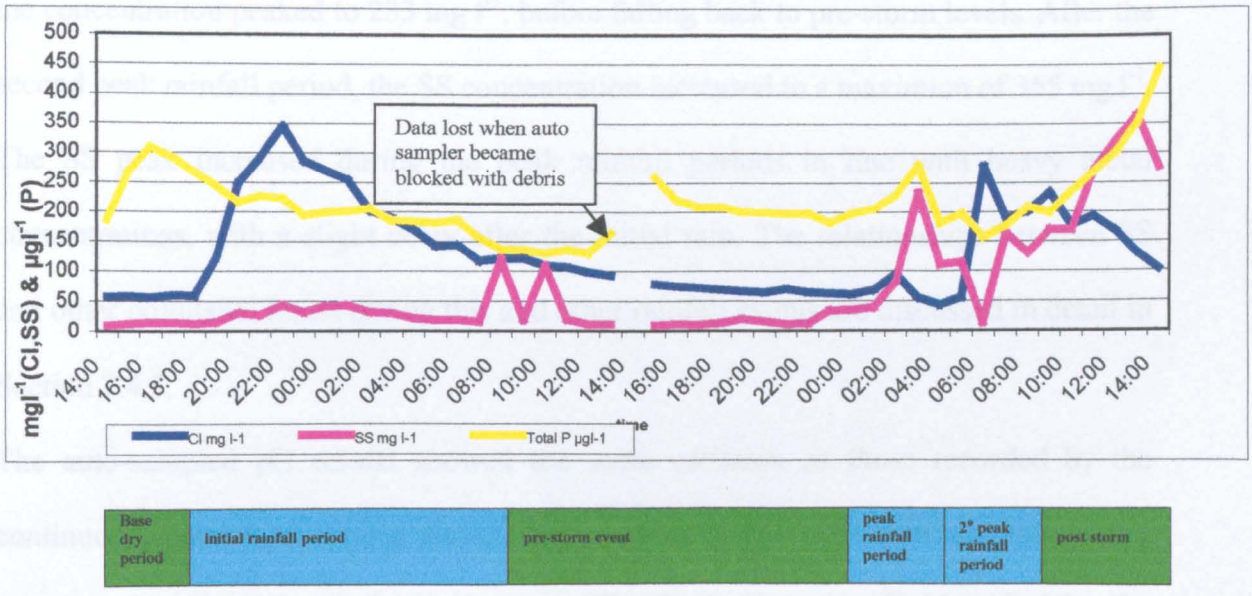
The relationships between the heavy metals and the sanitary determinands found during storm events in the River Sherbourne will be discussed in Section 7.4.1, as will the statistical significance of these relationships, overall trends, and the possible sources, based on previously published literature, as discussed in Chapter 2.

iv) Chloride, Suspended Solids and Total Phosphate

Sampled Cl concentration increased markedly from 60 mg l^{-1} during the dry baseline period, to a peak of 345 mg l^{-1} during the initial rainfall period. The level then decreased

steadily over the next 27 hours to initial levels before rising to lesser peaks of 277 mg l^{-1} and 233 mg l^{-1} during the peak rainfall and secondary peak rainfall events respectively. The results showed that the Cl peak occurred toward the end of the peak rainfall period rather than during the event itself, as was the case with the heavy metals. Since water is not abstracted for potable use there are no Cl limits applicable to the River Sherbourne, but the maximum level permissible under the Surface Waters (Abstraction for Drinking Water) Directions 1996, as required by the Surface Water abstraction Directive (SWAD) 75/440/EEC, would be 200 mg l^{-1} for all classes of abstraction. There is no intention at this time to abstract water from the River Sherbourne to supplement the public water supply. The results for Cl, SS and Total Phosphate are represented in Figure 7.9:

Figure 7.9 Auto-sample results – Cl, SS and Total P. Humber Ave 15-17 March 2001



Orthophosphate remained at non-detectable levels (< 0.5 mg l^{-1}) for the duration of the storm, but total P showed some variation during the peak rainfall period (Figure 7.9), with a maximum concentration of 280 mg l^{-1}, before falling slightly again. The concentration increased slightly during the 2nd peak rainfall period, and continued to rise

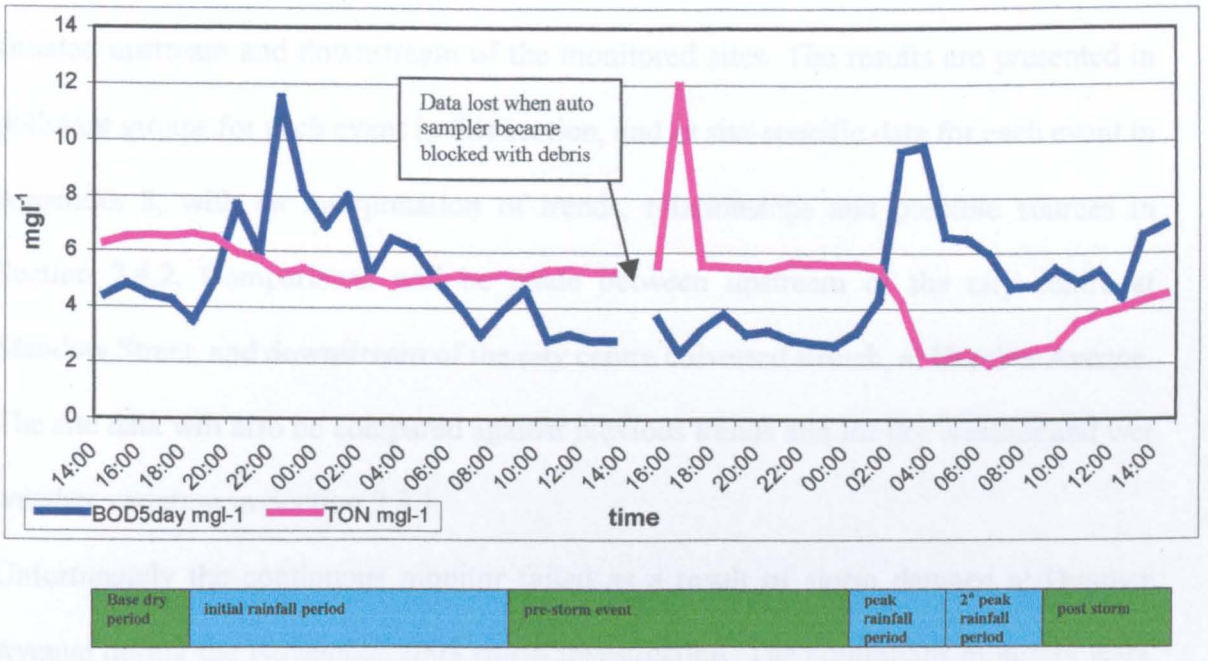
to a maximum of 445mg l^{-1} at the end of the sampling period. The range of values recorded for this investigation was 100- 450µg l^{-1}, which would equate to a Class 5 river under the GQA Nutrient Classification Scheme (Environment Agency, 2003), where a range of <0.2 – 1.0 mg l^{-1} is described as 'Very High'. The results for total P will be discussed in relation to the second hypothesis (Section 1.4) in Chapter 8. The river displayed other eutrophic characteristics during long-term river monitoring runs, including a very strong diurnal rhythm for Dissolved Oxygen and pH, which may indicate a healthy algal population.

The SS concentration followed a similar pattern to total P, with a marked increase in concentration towards the end of the sampling period (see Figure 7.9). The concentration rose to a maximum of 122 mg l^{-1} following the initial rainfall period, falling back to 20 mg l^{-1}or less for a period of 11 hours. During the peak rainfall period the concentration peaked to 233 mg l^{-1}, before falling back to pre-storm levels. After the second peak rainfall period, the SS concentration increased to a maximum of 365 mg l^{-1}. The SS peak increased during the peak rainfall periods in line with heavy metal concentrations, with a slight delay after the initial rain. The relationships between SS and other pollutants found during this and other rainfall events are discussed in detail in Section 7.4.1.

The auto-sampled pH results showed the same variation as those recorded by the continuous monitor, dropping during the initial rain and peak rainfall periods and returning to normal levels between them. The fluctuations in pH identified by the samples were not nearly as marked as those recorded by the continuous monitor. This could be due to the fact that the composite samples identify a more linear variation in pH over the period, against the more immediate 15-minute frequency recorded by the continuous monitors. This comparison will be discussed further in Section 7.4.1.

BOD showed an increase during the initial rainfall period, to a maximum of 11.5 mg l^{-1} at 22.00 hours on 15 March (see Figure 7.10). The concentration then dropped to an average of around 3mg l^{-1} until the peak rainfall period when a peak value of 9.83 mg l^{-1} at the height of the storm flow was achieved. The second, lower peak identified during the peak rainfall period was in line with SS and Total P analyses, which may indicate a high component of organic matter within the storm flow. A slightly higher concentration than was identified during the baseline period, was maintained following the storm event.

Figure 7.10 Auto-sample results – BOD and TON Humber Ave 15-17 March 2001



TON fell to one third of previous levels during the peak rainfall period, reaching a minimum concentration of 2 mg l^{-1} three hours after the peak rainfall level on 15 March 2001 (see Figure 7.10). The reduced concentration was extended during the second peak rainfall period, before rising slowly towards dry weather (baseline) levels. The pattern of fluctuation was similar to that of ammonium as determined by the continuous monitor (Figure 7.5).

7.2.2 Dry weather investigation September 2003

i) Introduction

The dry weather investigation was carried out over a 12 hour period on 30 September 2003, to obtain a more recent evaluation of water quality in the urban River Sherbourne. With the storm event monitored over 25-26 November 2003, this investigation presented an opportunity to compare dry weather pollutant concentrations at Meadow Street and Humber Avenue, against wet weather conditions at both sites. In comparison to earlier investigations, an increased resource in sampling equipment and continuous monitors became available, plus flow data provided by new fixed river level recorders, situated upstream and downstream of the monitored sites. The results are presented in pollutant groups for each event in this section, and as site-specific data for each event in Appendix 8, with an interpretation of trends, relationships and possible sources in Section 7.4.2. Comparisons will be made between upstream of the city centre at Meadow Street, and downstream of the city centre culverted stretch, at Humber Avenue. The site data will also be compared against previous trends and for dry weather and wet weather variation in Section 7.3.1.

Unfortunately the continuous monitor failed as a result of storm damage at Humber Avenue during the November 2003 storm investigation. The continuous monitors were withdrawn from use for economic reasons by the Environment Agency shortly afterwards, which did not permit a repeat of the investigation at a later date. The results for the 2003 investigations are given in Appendices 8, 9 and 10 and discussed briefly in Sections 7.2.2ii) to 7.2.2xv) below.

ii) River data and Rainfall

The rainfall for the period of investigation was zero (Figure 7.11), and the river level decreased only very slightly over the 12-hour study, with no sudden increase from local sources, as shown in Figure 7.12.

Figure 7.11 Rainfall Dry weather event September 2003

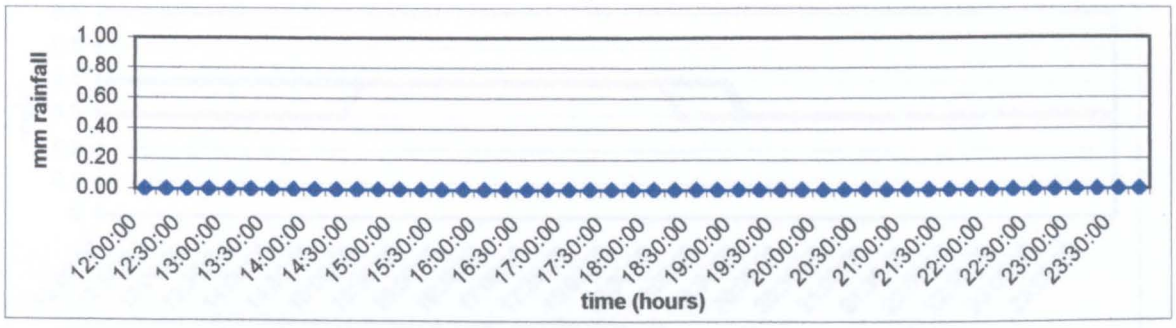
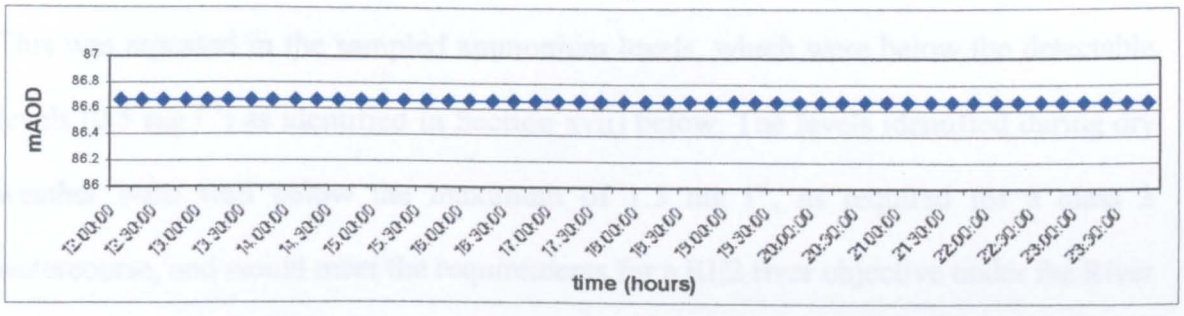


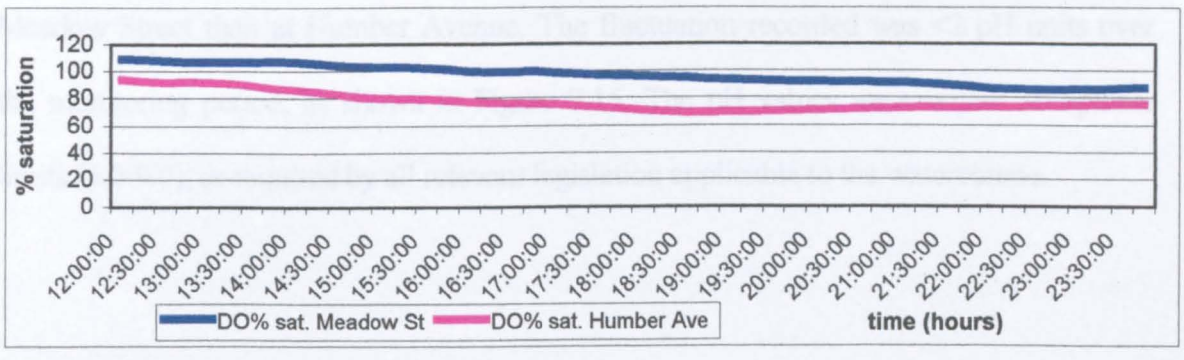
Figure 7.12 River level Kingsbury Avenue September 2003



iii) Continuous DO concentrations dry weather Meadow St. (upstream of city) and Humber Avenue (downstream of city) September 2003

The DO percentage saturation (Figure 7.13) decreased slowly over the monitoring period at both sites with levels at Meadow Street consistently higher than at Humber Avenue. Minimum levels were >60% saturation, as identified for a class C river (Section 2.4.2).

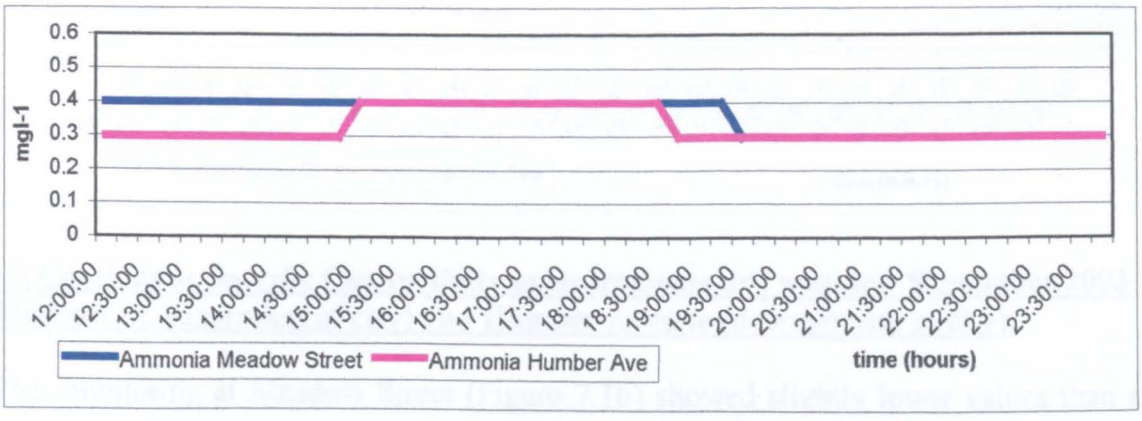
Figure 7.13 Continuous monitoring–Dissolved Oxygen saturation September 2003



iv) Continuous ammonium concentration dry weather September 2003 Meadow St. (upstream of city) and Humber Avenue (downstream of city).

Changes in ammonium were again minimal, with levels of no more than 0.4 mg l^{-1} identified at both monitoring sites, as shown in Figure 7.14.

Figure 7.14 Continuous monitoring– ammonium September 2003



This was repeated in the sampled ammonium levels, which were below the detectable levels (0.5 mg l^{-1}) as identified in Section xvii) below. The levels identified during dry weather were well below the maximum of 1.3 mg l^{-1}, as required for a class 3 watercourse, and would meet the requirements for a RE2 river objective under the River Ecosystem classification system, as identified in chapter 2. The maximum value of 0.4 mg l^{-1} is within the ammonium guideline figure of 0.78 mg l^{-1} for cyprinid waters, as identified by the EC Freshwater Fish Directive (78/659/EEC).

v) Continuous pH measurements dry weather September 2003 Meadow St. (upstream of city) and Humber Avenue (downstream of city).

The pH results showed a slight diurnal variation with levels consistently higher at Meadow Street than at Humber Avenue. The fluctuation recorded was <2 pH units over the monitoring period, as shown in Figure 7.15. The pH values were within acceptable limits (6.0-9.0), as required by all relevant legislation applicable to the watercourse.

Figure 7.15 Continuous monitoring– pH September 2003

vi) Continuous Specific Conductivity measurements dry weather September 2003 Meadow St. (upstream of city) and Humber Avenue (downstream of city).

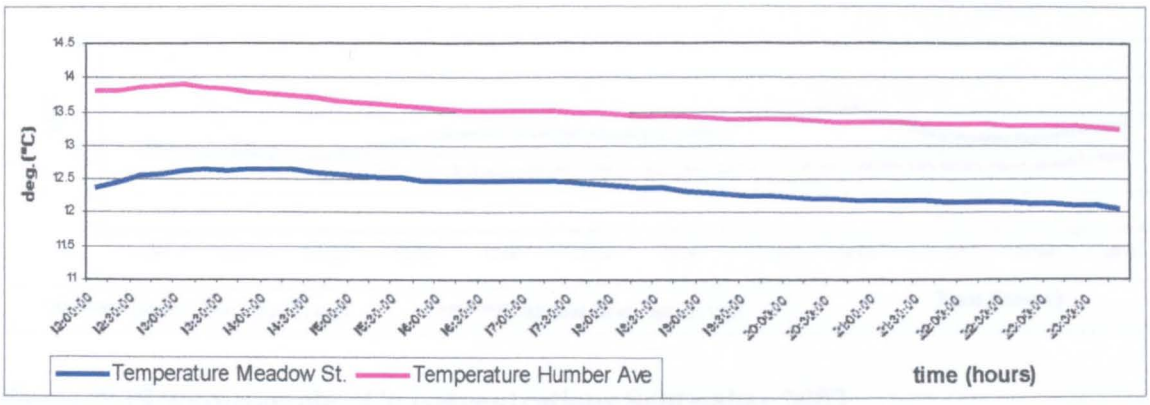
The monitoring at Meadow Street (Figure 7.16) showed slightly lower values than at Humber Avenue, but there was a single peak identified in the middle of the monitoring period, which did not occur for any other monitored pollutant, and as yet remains unexplained.

Figure 7.16 Continuous monitoring Specific conductivity September 2003 Meadow St. (upstream of city) and Humber Avenue (downstream of city).

vii) Continuous Temperature - dry weather September 2003 Meadow St. (upstream of city) and Humber Avenue (downstream of city).

The temperature at both sites decreased as evening progressed during the monitoring period. The temperature recorded at Meadow Street was slightly lower than that measured at Humber Avenue as shown in Figure 7.17:

Figure 7.17 Continuous monitoring–Temperature September 2003



viii) Heavy metal concentrations dry weather September 2003
Meadow St. (upstream of city) and Humber Avenue (downstream of city).

The Zn concentrations at both sites (Figure 7.18) were fairly static, after an initial high value at Meadow Street in the first sample. This high value was also reflected in the concentrations of Cu, Pb and to a lesser degree, Cr, as shown in Figures 7.18 to 7.20 below. The results correspond with a high SS concentration found in the first sample of the Meadow Street investigation, as shown in Figure 7.22. The initially high result may have been due to the displacement of settled solids in the culvert at the time of installation of the sampler, or it may have been due to an intermittent discharge of metal-containing effluent at this point. As there are no known 'wet' industrial processes in the immediate vicinity of the Meadow Street sampling point, it is suspected that the former explanation is more likely to be correct. It is not known whether any maintenance of the drainage system, or road gully pots, was in progress at this time. A smaller peak was then identified at Humber Avenue shortly afterwards, for most of the metals and SS, which may reflect the time of travel under these dry weather conditions, between the two points. The increase in Pb concentration shown in Figure 7.21 in the last sample, taken at 23.00 hours, is unexplained.

Figure 7.18 Auto-sample –Zn concentrations September 2003

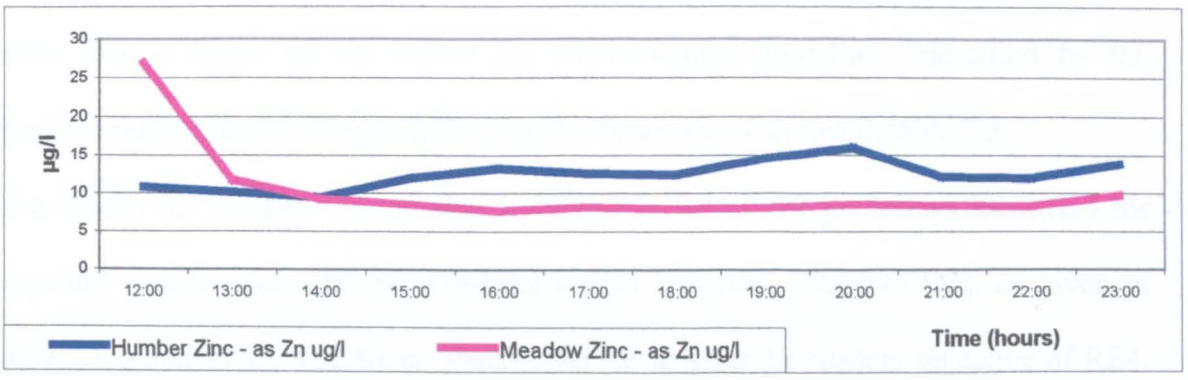


Figure 7.19 Auto-sample –Cu concentrations September 2003

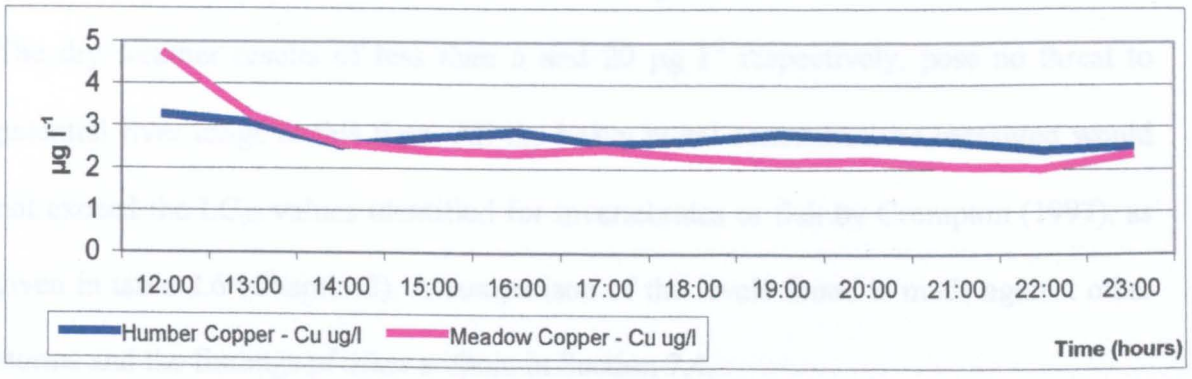


Figure 7.20 Auto-sample –Pb concentrations September 2003

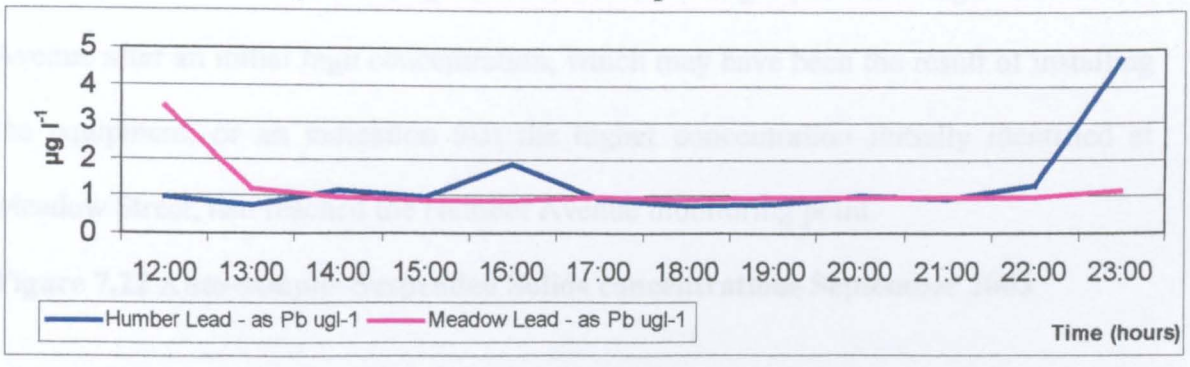
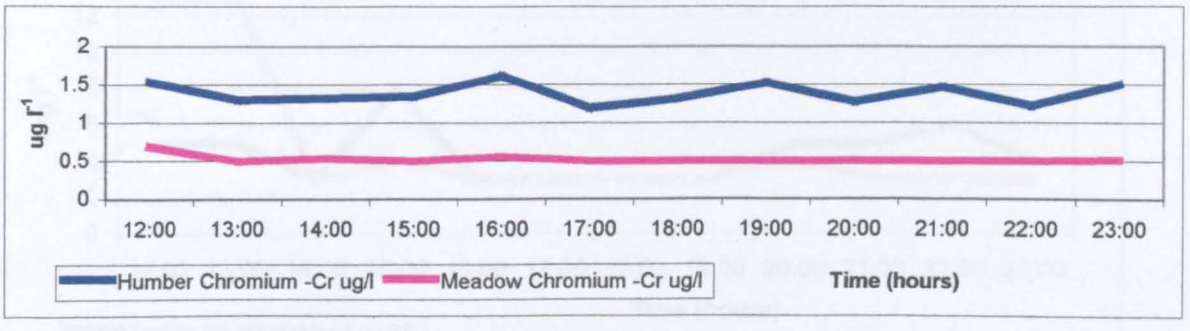


Figure 7.21 Auto-sample–Cr concentrations September 2003

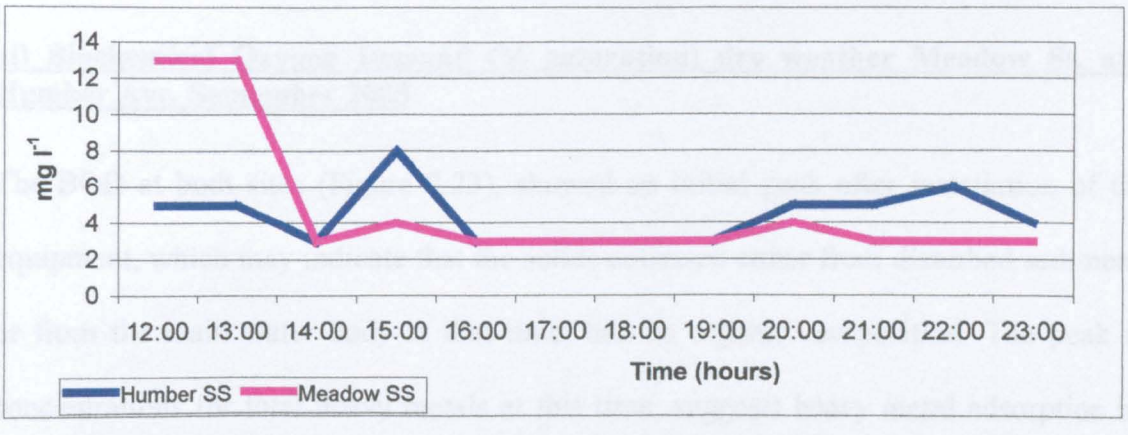


The heavy metal concentrations found during the period of dry weather are, in all cases, more than a factor of ten below the recommended guidelines identified by the Environmental Quality Standards for List II substances, as shown in table 7.2.

The results for Zn and Cu are also significantly below the guidelines identified for Cyprinid waters under the EC Freshwater Fish Directive (78/659/EEC), as given in table 2.9 (Chapter 2). The River Sherbourne has a River Ecosystem objective of RE4, with 95 percentile limits of 112 $\mu g\ l^{-1}$ for dissolved Cu, and 2000 $\mu g\ l^{-1}$ for Total Zn. The dry weather results of less than 5 and 20 $\mu g\ l^{-1}$ respectively, pose no threat to potential river usage at this time. All the heavy metal concentrations measured would not exceed the LC_{50} values identified for invertebrates or fish by Crompton (1997), as given in table 2.6 (Chapter 2). A comparison of the levels found is made against other storms and the findings of other authors in Section 7.4.

The suspended solids results (Figure 7.22) showed a slight peak to 8 $mg\ l^{-1}$ at Humber Avenue after an initial high concentration, which may have been the result of installing the equipment, or an indication that the higher concentration initially identified at Meadow Street, had reached the Humber Avenue monitoring point.

Figure 7.22 Auto-sample–Suspended Solids concentrations September 2003



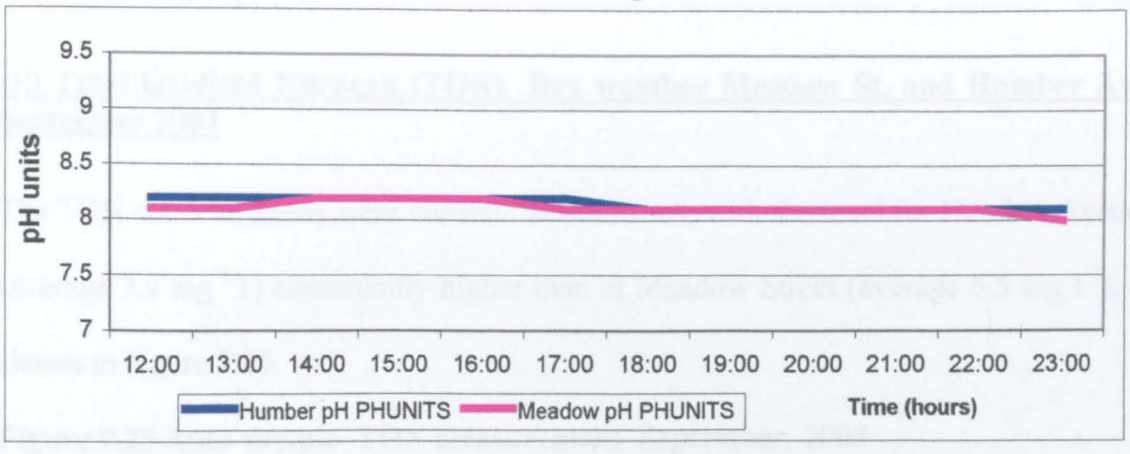
ix) Cadmium and ortho-phosphate concentrations dry weather, Meadow St. and Humber Ave. September 2003

Cadmium and orthophosphate were not detected at either Meadow Street or Humber Avenue sites during the dry weather investigation.

x) Sample pH measurements dry weather Meadow St. and Humber Ave. September 2003

Sampled pH (Figure 7.23) showed the same pattern for both sites as the continuously monitored pH measurements, though the variation in pH levels for samples was less than 0.2 pH units. This can perhaps be explained by the samples achieving equilibrium in the time before they were analysed, and also points to the data levelling effect of analysing composites, against real time continuous monitoring.

Figure 7.23 Auto-sample–pH measurement September 2003

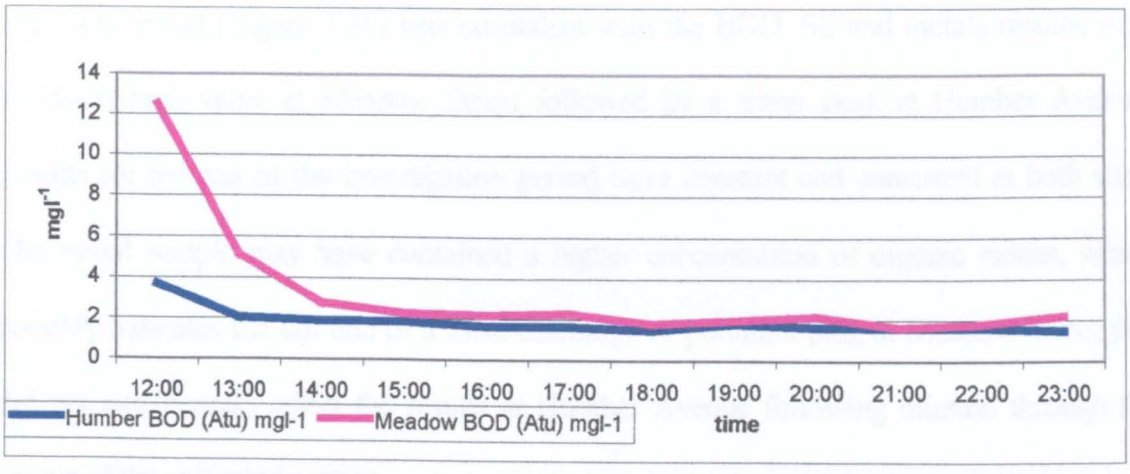


xi) Biochemical Oxygen Demand (% saturation) dry weather Meadow St. and Humber Ave. September 2003

The BOD at both sites (Figure 7.23), showed an initial peak after installation of the equipment, which may indicate that the solids collected either from disturbed sediment, or from the main water body at that time, had an organic composition. The peak in concentrations for total heavy metals at this time, suggests heavy metal adsorption by the suspended solids for some pollutants, as discussed in Section 2.2. The BOD of over

12 mg l^{-1} found in the first sample at Meadow Street exceeds the 90-percentile limit for a class C watercourse, but is generally exceptional in the findings during dry weather at both sites. If consistently measured at this level of BOD, the watercourse would fall within the quality objectives for a river ecosystem classification of RE4, which is currently the appropriate objective for this urban watercourse.

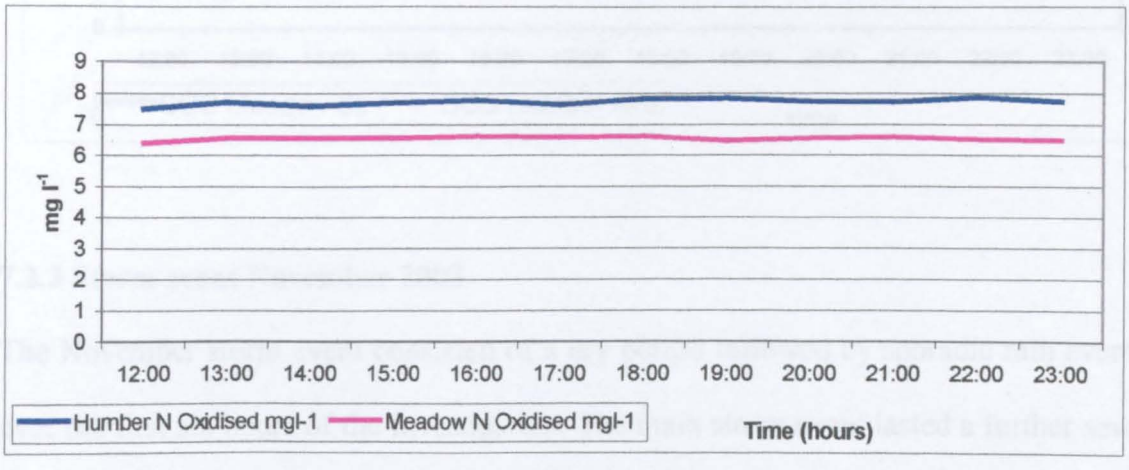
Figure 7.24 Auto-sample– BOD September 2003



xii) Total Oxidised Nitrogen (TON) Dry weather Meadow St. and Humber Ave. September 2003

The TON concentrations were constant at both sites, with the level for Humber Avenue (average 7.9 mg $^{l-}$1) consistently higher than at Meadow Street (average 6.5 mg l^{-1}), as shown in Figure 7.25.

Figure 7.25 Auto-sample–TON measurement September 2003



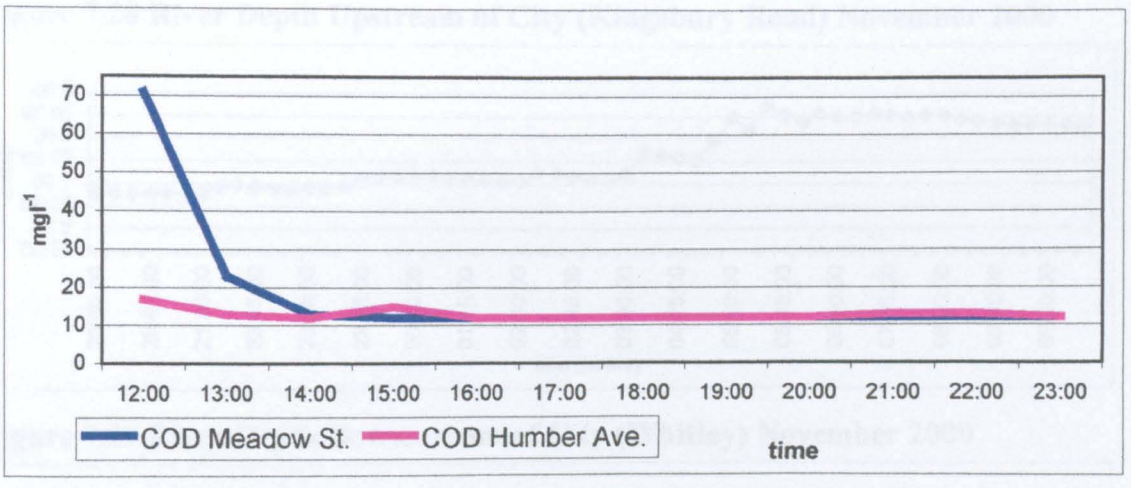
xiii) Sampled ammonium dry weather Meadow St. and Humber Ave. September 2003

Ammonium concentrations remained below the detection level of 0.5 mg l^{-1} at both sites. These results are consistent with the measurements recorded by continuous monitoring as shown in Figure 7.5.

xiv) Chemical Oxygen Demand Dry weather Meadow St. and Humber Ave. September 2003

The COD result (Figure 7.26) was consistent with the BOD, SS and metals results, with an initial high value at Meadow Street followed by a lesser peak at Humber Avenue. Results for the rest of the investigation period were constant and consistent at both sites. The initial sample may have contained a higher concentration of organic matter, which possibly indicates the tail end of a local discharge or pollutant plug at Meadow Street that did not significantly affect the results at Humber Avenue following dilution through the course of the culverted section.

Figure 7.26 Auto-sample COD September 2003



7.2.3 Storm event November 2003

The November storm event consisted of a dry period followed by sporadic rain events, over the first six hours of the investigation. The main storm event lasted a further seven hours, and reached a peak of 3.5 mm of rainfall per hour after 4 hours, before tailing off

again, as shown in Figure 7.27. The river level responded quickly to the storm event, and peaked upstream at Kingsbury Road and downstream at Whitley flow monitoring stations, in line with the peak of the storm event, as shown in Figures 7.28 and 7.29. The speed of the river level response indicates the high percentage of impervious areas draining to the main river channel in the city centre, as identified in Figure 2.2.

i) River data and rainfall

Figure 7.27 Coventry (Finham) STW Rainfall, November 2000 storm event

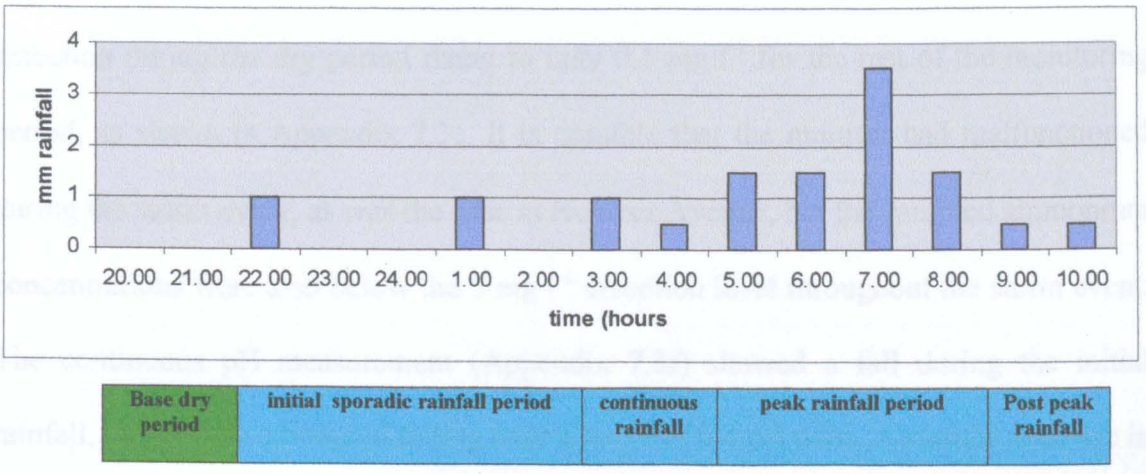


Figure 7.28 River Depth Upstream of City (Kingsbury Road) November 2000

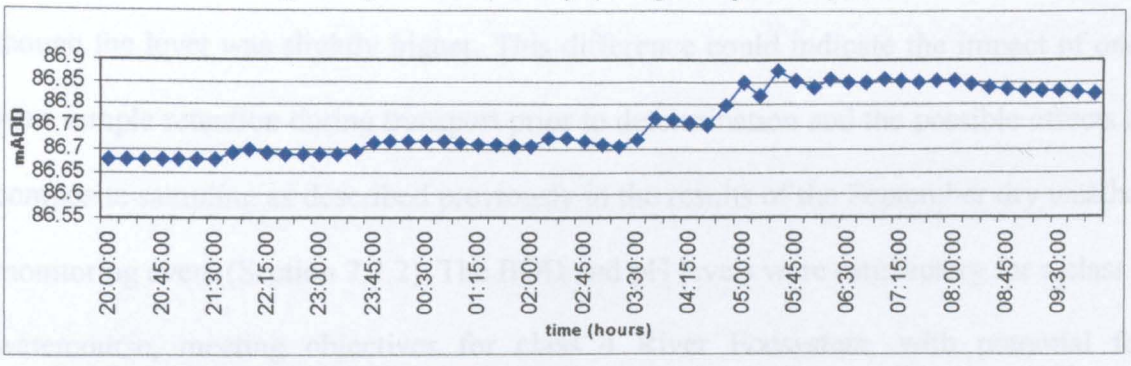
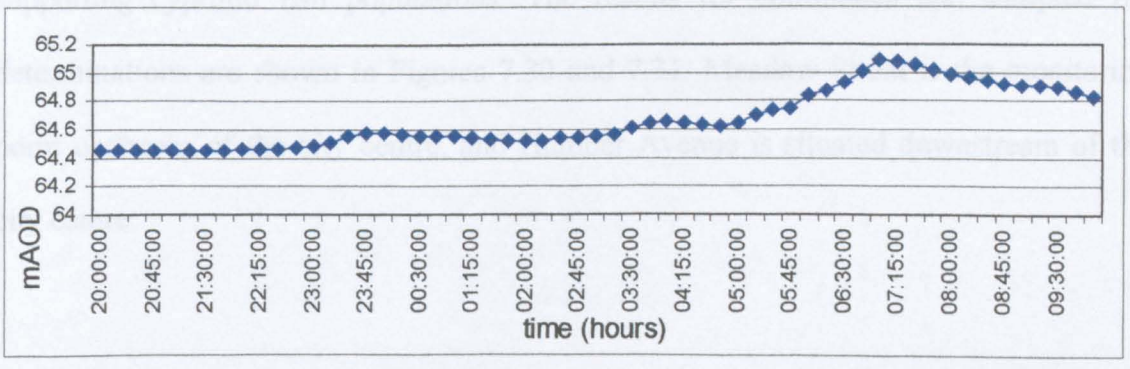


Figure 7.29 River Depth Downstream of City (Whitley) November 2000



ii) Sanitary Determinands

The storm event monitored in November did not have a major impact on the levels of Dissolved Oxygen saturation, ammonium, pH or specific conductance. The results of the investigation are presented in Appendix 7. The Dissolved Oxygen saturation remained above 90%, with only a minor dip during the initial night-time rainfall period, before returning to supersaturation levels at 120% during daylight hours, as shown in Appendix 7.3d. The ammonium monitor indicated ammonium levels below the level of detection during the dry period rising to only 0.1 mg l^{-1} for the rest of the monitoring period, as shown in Appendix 7.3e. It is possible that the monitor had malfunctioned during the storm event, as was the case at Humber Avenue, but the sampled ammonium concentrations were also below the 5 mg l^{-1} detection level throughout the storm event. The continuous pH measurement (Appendix 7.3f) showed a fall during the initial rainfall, which then continued falling over a range of 0.4 pH units. A similar decrease in pH was identified in the sampled pH measurements at both sites (Appendix 7.2i)), though the level was slightly higher. This difference could indicate the impact of one-hour sample retention during transport prior to determination and the possible effects of composite sampling as described previously in the results of the September dry weather monitoring event (Section 7.2.2). The BOD and pH levels were satisfactory for a class 3 watercourse, meeting objectives for class 4 River Ecosystem, with potential for supporting cyprinid fish populations. The results for continuous and sampled pH determinations are shown in Figures 7.30 and 7.31. Meadow Street is the monitoring point upstream of the city centre, and Humber Avenue is situated downstream of the city centre.

Figure 7.30 Continuous pH at Meadow Street, storm event November 2003

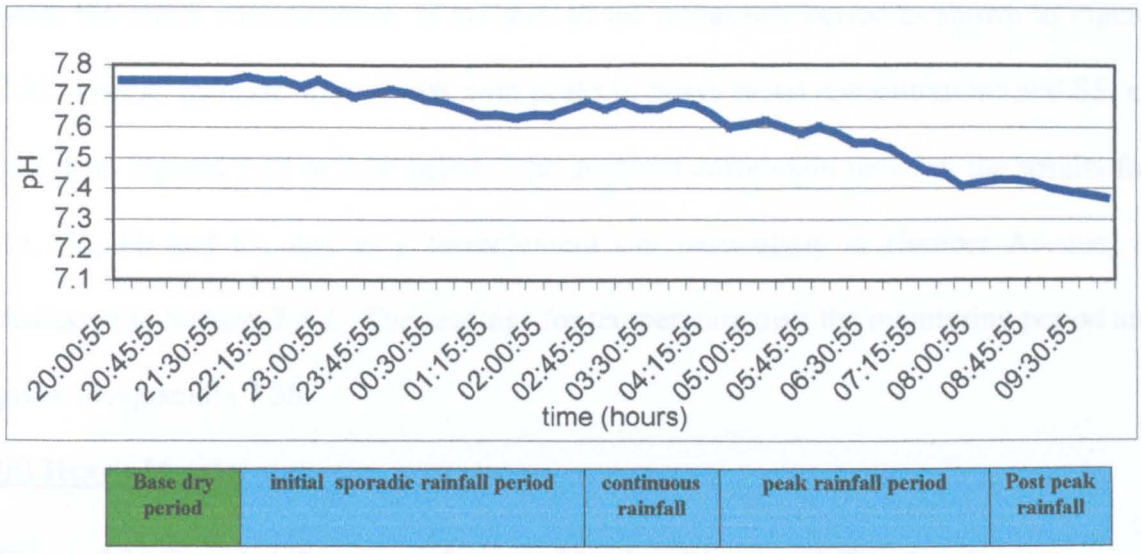


Figure 7.31 Sampled pH comparisons at Meadow Street and Humber Avenue during storm event November 2003

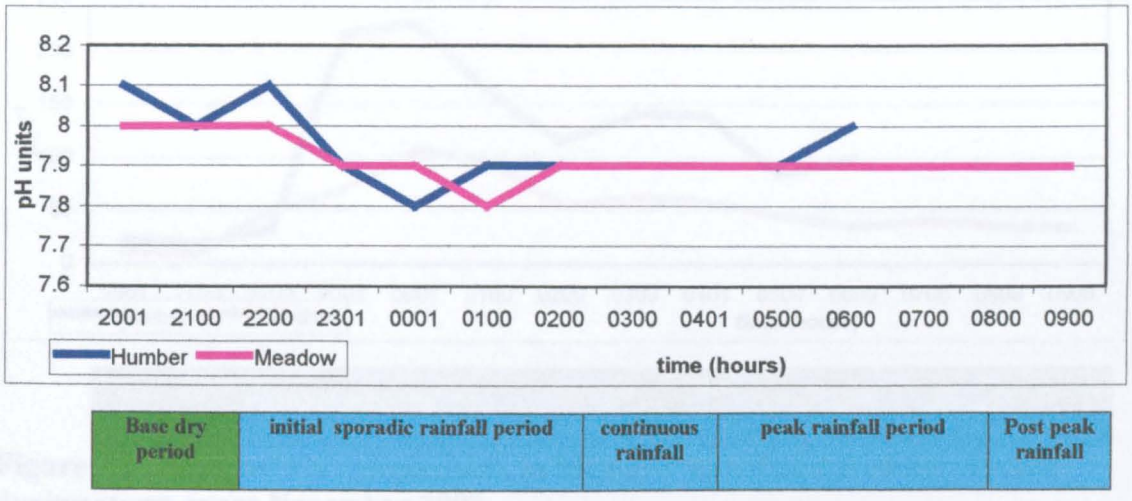
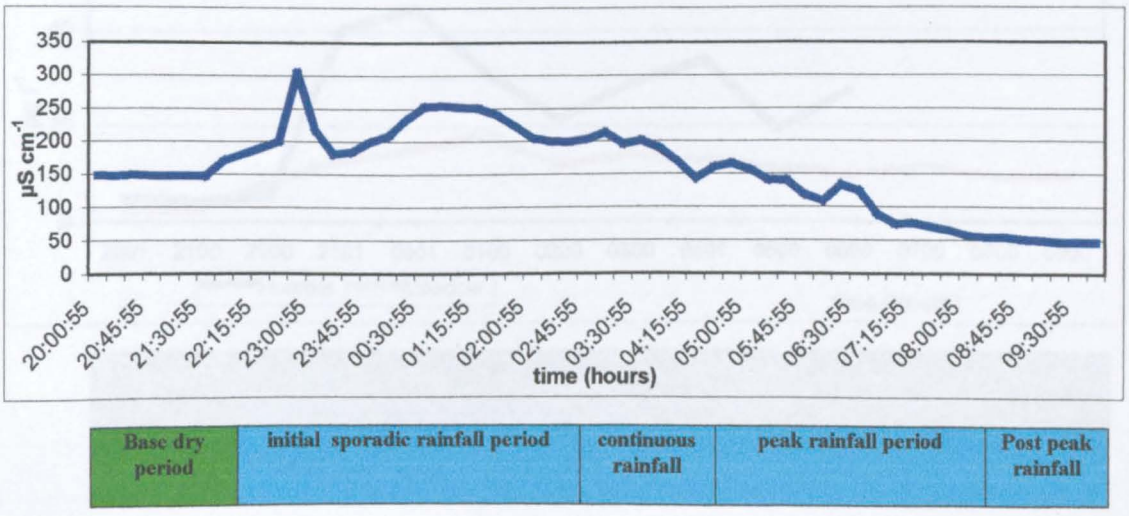


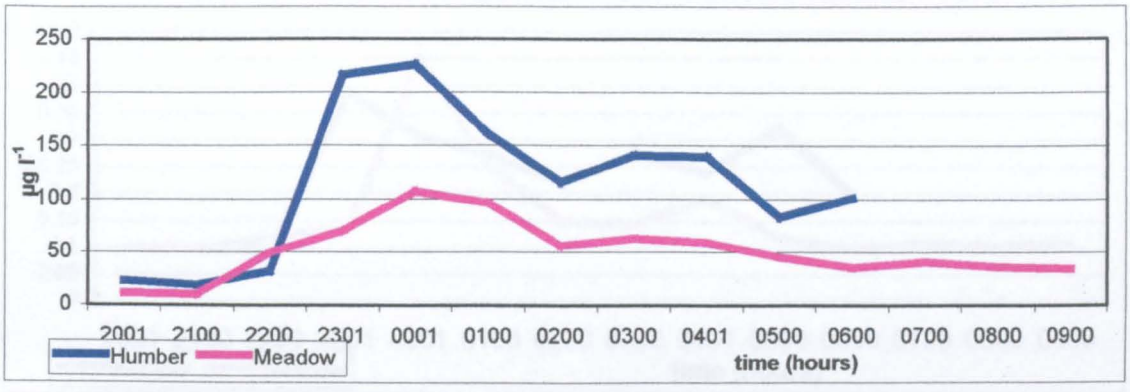
Figure 7.32 Continuous specific conductivity Meadow St. storm event November 2003



Specific Conductivity levels also decreased continuously after a significant peak at twice the initial concentration, at the start of the initial rain period as shown in Figure 7.32. The SC increase corresponds with peaks in heavy metal concentrations and SS, as shown in Figures 7.33 to 7.38 below. The apparent correlation between the results for Zn, Cu, Pb and Cr, and to a lesser extent Cd, particularly at Humber Avenue, is discussed in Section 7.4.2. The readings for temperature over the monitoring period are given in Appendix 7.3h.

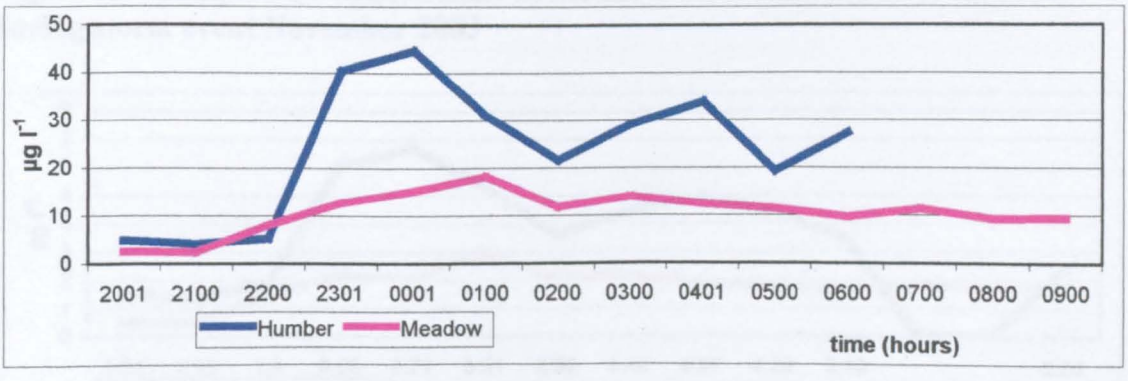
iii) Heavy Metals

Figure 7.33 Sampled Zn comparisons at Meadow Street and Humber Avenue during storm event November 2003



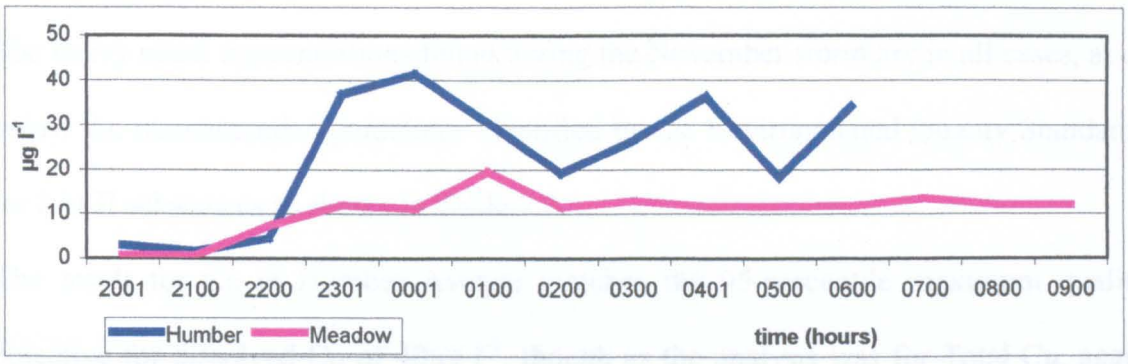
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure 7.34 Sampled Cu comparisons at Meadow Street and Humber Avenue during storm event November 2003



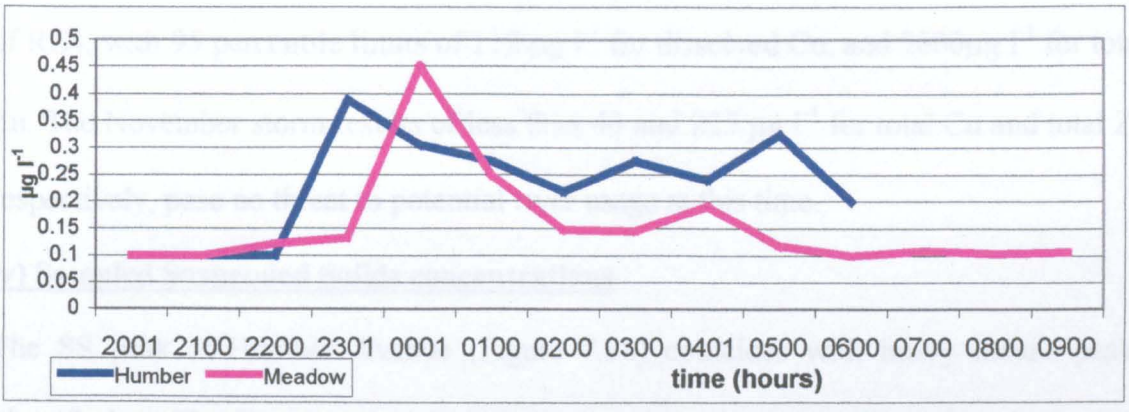
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure 7.35 Sampled Pb comparisons at Meadow Street and Humber Avenue during storm event November 2003



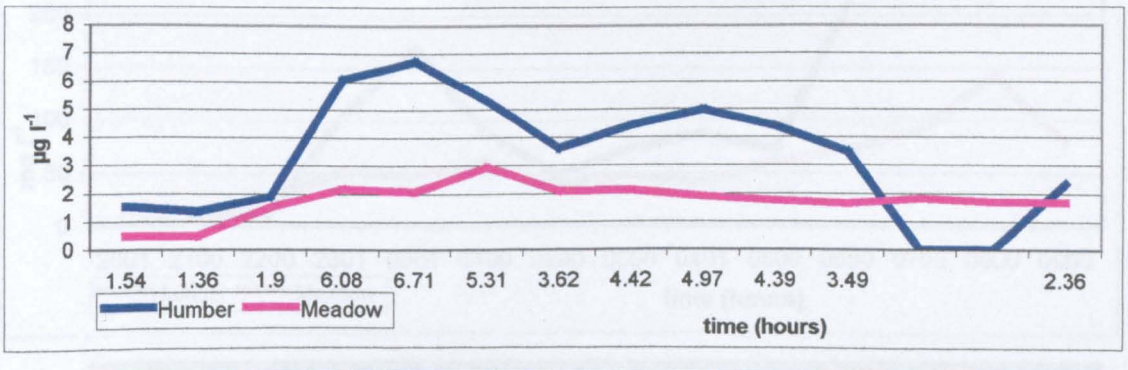
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure 7.36 Sampled Cd comparisons at Meadow Street and Humber Avenue during storm event November 2003



Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure 7.37 Sampled Cr comparisons at Meadow Street and Humber Avenue during storm event November 2003



Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Total Ni concentrations were below the detectable limit of 5 $\mu g\ l^{-1}$ at both sites for the duration of the event.

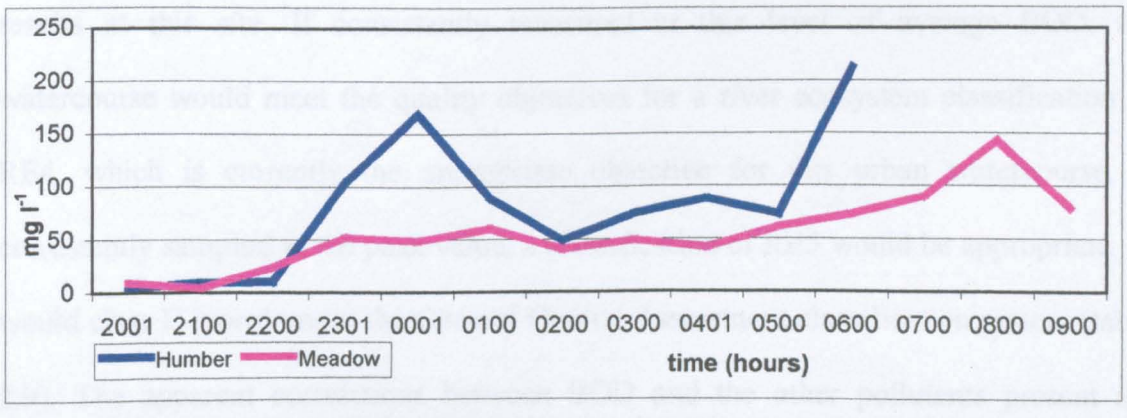
The heavy metal concentrations found during the November storm are in all cases, at or below the recommended guidelines identified by the Environmental Quality Standards for List II substances as shown in Table 7.2.

The result for Cu at Humber Avenue matches the 95-percentile maximum quality objective for dissolved Cu of 40$\mu g\ l^{-1}$, though as the analysis was for Total Cu, again the objective was not breached. The results for Zn and Cu are also below the guidelines identified for Cyprinid waters in the EC Freshwater Fish Directive (78/659/EEC) as given in table 2.9 (Chapter 2). The River Sherbourne has a River Ecosystem objective of RE4, with 95 percentile limits of 112 $\mu g\ l^{-1}$ for dissolved Cu, and 2000$\mu g\ l^{-1}$ for total Zn. The November storm results of less than 40 and 225 $\mu g\ l^{-1}$ for total Cu and total Zn respectively, pose no threat to potential river usage at this time.

iv) Sampled Suspended Solids concentrations

The SS peak at Humber Avenue (Figure 7.38) coincides with heavy metals peaks identified at Humber Avenue during the November storm event. The relationship between these pollutants is discussed further in Section 7.4.2.

Figure 7.38 Sampled SS comparisons at Meadow Street and Humber Avenue during storm event November 2003



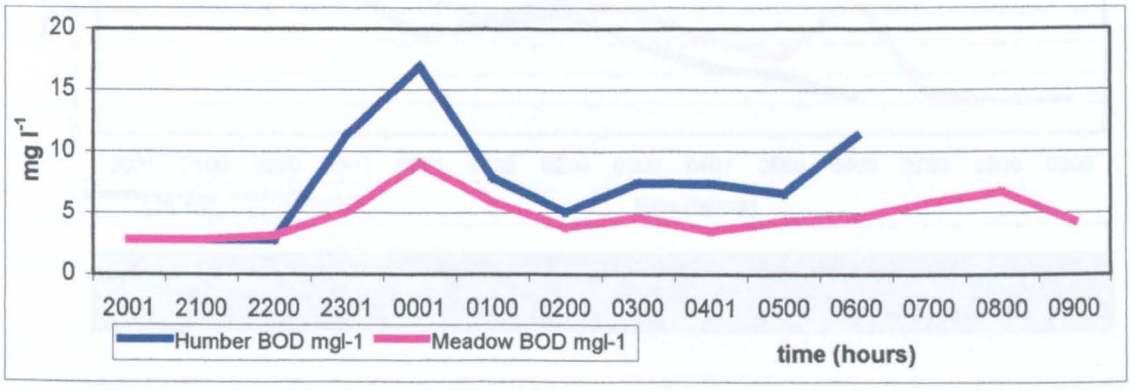
v) Sampled ortho-phosphate concentrations

Ortho-phosphate was below the detectable limit of 0.5 mg l^{-1} at both sites.

vi) Sampled Biochemical Oxygen Demand

The peak level BOD at Humber Avenue occurred at the same time as the peak concentrations for SS and metals, as shown in Figure 7.39.

Figure 7.39 Sampled BOD comparisons at Meadow Street and Humber Avenue during storm event November 2003



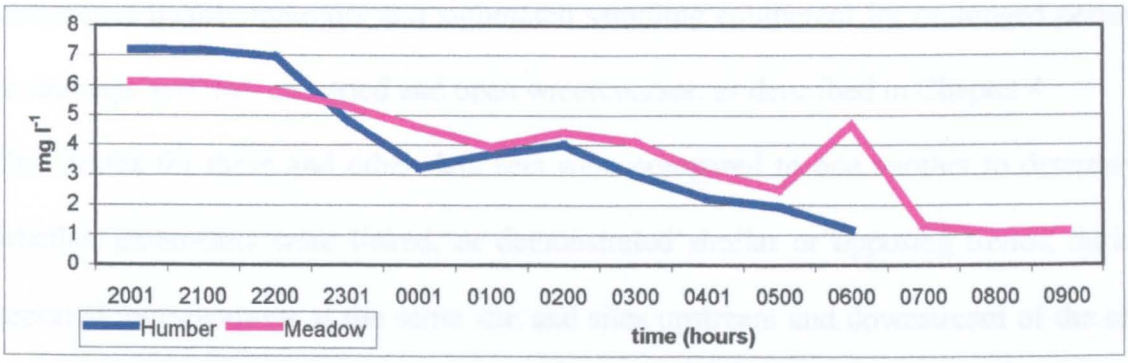
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

As in the storm event of March 2001, the SS appear to have been of organic composition (exerting an oxygen demand during analysis), with heavy metal adsorption evident for some pollutants. The BOD of over 15 mg l^{-1} found at Humber Avenue exceeds the 90-percentile limit for a class C watercourse, as do the rest of the sampled results at this site. If consistently measured at this level of average BOD, the watercourse would meet the quality objectives for a river ecosystem classification of RE4, which is currently the appropriate objective for this urban watercourse. If consistently sampled at the peak value, a classification of RE5 would be appropriate, as would class E (poor) under the General Quality Assessment classification system (table 2.9). The apparent correlations between BOD and the other pollutants present are discussed further in Section 7.4.2.

vii) Sampled Total Oxidised Nitrogen

TON concentrations for both sites decreased over the monitoring period, as shown in Figure 7.40, with a small peak detected at Meadow Street before a further reduction in concentration after the storm event.

Figure 7.40 Sampled TON comparisons at Meadow Street and Humber Avenue during storm event November 2003



Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

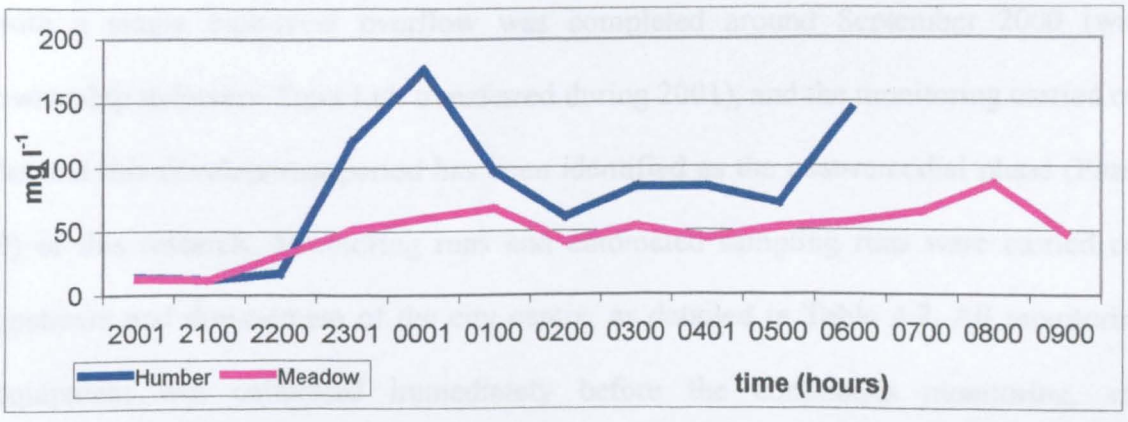
viii) Sampled ammonium concentration

Ammonium concentrations were below the detectable limit of 5 mg l^{-1} at both sites.

ix) Sampled Chemical Oxygen Demand

The trend for Chemical Oxygen Demand (Figure 7.41) closely mirrored the result for BOD at both sites as discussed in Section 7.2.3vi).

Figure 7.41 Sampled COD comparisons at Meadow Street and Humber Avenue during storm event November 2003



Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

7.3 Conclusions and statistical analysis of the results for the River Sherbourne investigations during Phase 3.

Introduction

This section discusses the results for Phase 3, and explores the relationships between environmental conditions and the concentrations of pollutants identified, using continuous quality monitors and automated sampling equipment for prolonged periods in drainage systems, culverted and open watercourses, as described in Chapter 4.

The results for these and other data sets were compared to one another to determine whether parameters were linked, or demonstrated similar or opposing trends, during repeated investigations at the same site and sites upstream and downstream of the city centre culverted stretch of the River Sherbourne. Hydrological data is often not normally distributed (Charlesworth & Lees, 1999) and the results were analysed using the non-parametric Spearman's test for rank correlation, to identify significant correlation (with each other), to 95% and 99% confidence levels. The correlation data is summarised in Tables 7.3 to 7.5.

7.3.1 Post remedial data collection, October 2000 to November 2003

The replacement of the six unsatisfactory combined sewer overflows at Albany Road with a single high-level overflow was completed around September 2000 (with ownership to Severn Trent Ltd. transferred during 2001), and the monitoring carried out beyond this development period has been identified as the post-remedial phase (Phase 3) of this research. Monitoring runs and automated sampling runs were carried out upstream and downstream of the city centre, as detailed in Table 4.7. All monitoring equipment was calibrated immediately before the continuous monitoring, and comparison of trends for upstream and downstream monitoring was used for quality

control of monitoring data. The results from all of the 17 post-remediation runs are shown in Appendices 6.1- 6.16, and summarised in Table 7.1, and a summary of the highly significant and significant correlations for the post remedial investigations (derived from the application of the Spearman's correlation test to each investigation run) is given in Table 7.3 and 7.4) (auto-sample runs 6-11) and Table 7.5 (continuous monitor runs C1 –C11). Rather than identify individual r^2 (significance) values for each variable comparison, a significant result is represented as 0, and a highly significant result represented as –1 or 1, with the null hypothesis of no relationship between two variables not shown. In this way the number of significant and highly significant correlations for each relationship during different individual runs can be easily identified, giving an indication of the strength of the relationship between different sites, parameters and weather conditions, over a number of investigations.

Generally the results show that during a rainfall event, BOD increases with SS, Cd, Cu and Zn. Cr is linked with SS concentrations during wet and dry conditions, and Cu and Zn appears to be linked to SS during storm events. The upstream ammonium concentration appears to increase with increased river depth, whereas downstream the concentration falls consistently with highly significant results ($p > 0.01$) showing negative correlation against river depth in the Spearman's correlation analysis. This may be due to the lag time between the monitoring point and the location of the depth monitor at the downstream monitoring point. This potential problem was addressed in later investigations (Section 7.4.2) by the use of upstream and downstream depth measurement at Kingsbury Road and Whitley (Figure 3.2), and adjusted correlation data against river depth and rainfall data, to compensate for variable lag times in flow, and transportation of rainfall via local drainage to the watercourse, between the two points.

Table 7.3 Spearman rank correlations for post remedial sample results from investigations Auto 6-11

sampled														
BOD	BOD													
NH_3N		NH_3N												
SS	101101		SS											
Ortho-P	1		11	Ortho-P										
pH	-1-1-1-1	1	-1-1-0-1	1	pH									
Total Cd	1010		110	1	-0-1	Total Cd								
Total Cr	10111		11111	-1	-0-0-1-1 -1-1	111111	Total Cr							
Total Cu	1111111 0		111011	1	-1-1-1-1 -1-1	11111	1111	Total Cu						
Total Zn	11111	-1	1111	1	-1-1-1-1	1111	11111	11111	Total Zn					
Total Ni	-1		1-1		-11	11	-1	-1	-1	Total Ni				
rainfall	0-0		0	-1		1	00	01	01		rainfall			
depth	101		111	1-1	-0-0-1-0	0	010	1	1	1		depth		
TON	-1-1-1	-1	-1-1	1	111	-1	-1-1-1	-0-0-1-1	-1-1-1-1	1	-0	-1-1	TON	
Total P	1110	-1	111	1	-0-1	1101	01	11-1	00-1	1	0	-11	-1	Total P
Total Pb	1111		1111	1	-1-1-1	111	1111	1111	1111	-1	01	11	-1-1-1	001
Chloride	111		1-011	-1	-1-1-1		11	111	111	-1	0	1-111	-10-1-1	11

Total Pb														
1	Chloride													

Key	Storm 1=Highly Significant p≤0.01; 0=Significant p ≤0.05 Dry weather 1=Highly Significant p≤0.01; 0=Significant p ≤0.05	100% Consistent trend	≥ 50% consistent trend	Single significant or highly significant result

Key to table:
1 = highly significant positive correlation during single run
-1 =highly significant negative correlation during single run
0 indicates a positive or negative (-0) significant correlation
US = upstream of city; DS= downstream of city

Table 7.4 Spearman rank correlations for post remedial sample results for investigations Auto 6-11 and associated continuous results.
(Correlations between continuous data only detailed in table 7.5 C1 –C11 continuous monitor runs)

Continuous sampled	US DO%	US NH_3N	US pH	US spec.cond.	DS DO%	DS NH_3N	DS pH	DS spec.cond.	US TDS	US Temp	DS TDS	DS Temp
BOD	-1	0	-0	-1	-0-0-11	1	-1	-1		1	0-1-0	01-1
NH_3N		-1	-1		1	-1				-1	1	
SS	-11-0		-11-1	-10	-1-1		-1-1	-1	-00	1-1	1-1	11
Ortho-P			-0	-1	0		-0	-1	-1			
pH	00	-1	1	0	1		1		0-0	01-10	1	-10
Total Cd	1-0		01-1				-1		00	00-0		00
Total Cr	0-1		-1		-1		-1		1	01-1	-1	1
Total Cu	-1	00		-0	-10	0				01	-1	11-1-0
Total Zn	-0	00		-0	-1					0	-1	1
Total Ni						-1						
rainfall		0			0	0		0				0
depth	-111	-10-1	-1-01-1	-1	1-11	-1-1	-1-1	-11	1-1-1	-1-1	1-1-1	0-11-1
TON	0-01	-01	01		1	1	001		-11-1	1-11	11	1-1
Total P	-0	01	0		-1-1	0			0	1	-0-1	1
Total Pb	0-1	00	-1		-1	0	-1			11-1	-1	01
Chloride	-1-1	10-1	-1-1		-1-10	11	-1-0		11-0	11	11-1-0	11

Key				
Storm 1=Highly Significant p≤0.01; 0=Significant p ≤0.05 Dry weather 1=Highly Significant p≤0.01; 0=Significant p ≤0.05	US = upstream of city DS= downstream of city	100% Consistent trend	≥ 50% consistent trend	Single significant or highly significant result

Table 7.5 Spearman rank correlations for post remedial investigation numbers C1 – C11 (continuous monitor data only)

Key to table:
1 = highly significant positive correlation during run
-1 = highly significant negative correlation during run
0 indicates a positive or negative (-0) significant correlation
numbers in brown indicate a dry weather investigation run
US = upstream of city; DS= downstream of city

Continuous										
US DO%	US DO%									
US NH3	-1-1-1-1-1 -1-0	US NH3								
US pH	111111111 -11	-1-1-1-0-1 -1-1-1-110	US pH							
US TDS	111-1-11 -11-1-1	-1-1-11-1 -1111	111111111 1-1	US TDS						
US Temp	1-11-11-1 1-1	11111-11 1111	-1-11-1-11 -1111	-01111111 -1	US Temp					
DS DO%	111111111 11	-1-10-1-1 -1-1-0	111111111 -11	-1-01-1-1 -11-1-1-1-0	1111-1111 -1-1	DS DO%				
DS NH3	1-1-1-1-1 -1-1-1-1-1	111111111 1	1-1-1-1-1 -1-1011	11111-1-1 111	1111-11 -1111	-0-1-1-1-1 1-1-1-1-1-1	DS NH3			
DS pH	11111111 -1-11	-1-11-1-1 -111	111111111 11	111111111 -1	-111-11-1 1-111	1-111111 11-11	1-11-11-1 -1-01	DS pH		
DS TDS	111-1-1-1 1-1-1-1-1	-1-1-11-1 -1-11	1111111-1	111111111 11	-1111111 -0	-11-1-1-1 -1-1-1-1	111-1-111 1	11111-111 1-1-1	DS TDS	
DS Temp	1010-1-0 -1-1-1	11111-111 110	1-1-11-1-1 -110	11111111	111111111 1	1111-1-1 -0-1-1-1-1	111-11-01 11	111-1-10-1 10	1111111	DS Temp
Depth D/S only	1111-1111 -1	111-11111 -1	-1-1-1-1-1 -11-1-11-0	-1-1-1-1-1 -1-1-1-0-11	11111-111 -1	11111111	-1-11-111 1-1-1-1	-1-1-0-11 -1-1-1-1	-1-11-1-1 -1-1-1-11	11111-111 -10

Key	Storm 1=Highly Significant p≤0.01 ; 0=Significant p≤0.05 Dry weather 1=Highly Significant p≤0.01; 0=Significant p≤0.05	100%Consistent trend	90 – 95% consistent trend	80- 89% consistent trend	<80% consistent trend

The introduction of unknown ammonium sources at the upstream monitoring point is also a possibility during the wet weather events, to a lesser degree than experienced previously (Phase 2), but in line with previous monitoring runs at this site. The effects are much reduced, with a lower average ammonium concentration, and less impact on the watercourse downstream than in Phase 2. The DO generally increased at the upstream and downstream monitoring points with increased flow, in contrast to the early monitoring and pre-remedial data, indicating an overall improvement in water quality, and a reduction in organic load discharging to the watercourse. The data for sanitary determinands identified in each phase of the research is given in Table 7.6:

Table 7.6 Descriptive statistics for early, pre-remedial and post-remedial data during Coventry storm events

Research phase		DS DO mg l^{-1}	DS $NH_4^+(N)$ mg l^{-1}	DS pH PH units	GQA routine	
					DO % saturation	NH_4^+N mg l^{-1}
Early data 1996-1997	max	118.80	14.7	9.1	-	-
	min	39.1	0.9	3.85	-	-
	mean	48.60	1.97	8.07	87.89	0.18
Pre-remedial 1999-Sept 2000	max	108.0	2.4	8.59	-	-
	min	71.8	0.1	7.20	-	-
	mean	73.36	0.51	7.80	93.33	0.09
Post-remedial Oct 2000-2003	max	152.1	1.7	9.86	-	-
	min	29.5	0	7.04	-	-
	mean	80.87	0.33	7.83	96.44	0.11
GQA Class C 95 percentile		> 60	< 1.3	6-9	--------	

A summary of the descriptive statistics for each phase are given in Tables 6.3 –6.4, 6.5-6.8, and 7.4 to 7.6 respectively. The post-remedial monitoring runs show an improved mean concentration for DO saturation below the city, but the minimum levels still reflect that with the high level storm overflow in place, and the likelihood of other

unidentified illegal discharges to the river system, the potential for oxygen depletion is still present.

Fundamental Intermittent Standards (FIS) for DO (Table 2.11), are given in mg l^{-1}, whereas the minimum concentration given for the post-remedial phase identified in Table 6.4 is expressed in terms of percentage saturation. The minimum DO value for Phase 3, (where blockage of equipment by debris had not occurred), was obtained during run C11. Readings below 40% were measured continuously for 4.5 hours during wet weather, with a water temperature of approximately 13°C. At 10°C, 100% saturation of DO equates to a concentration of 11.3 mg l^{-1} (Tebbutt, 1977), which gives an approximate saturation value of 10mg l^{-1} at 13°C. A percentage saturation of 40% therefore equates to 4mg l^{-1}, which is the minimum 1-hour duration Fundamental Intermittent Standard identified by the UPM methodology (FR/CL 0002.FWR, 1994) (Section 2.5.1), for a monthly return period. The DO concentration fell below this required minimum level for a continuous period of 4 hours, which would constitute a breach of the UPM standards shown in Table 2.12. The minimum value of <3mg l^{-1} was close to breaching the yearly return standard, and would have done so, had it been prolonged for over 1 hour. The mean value of 0.33mg l^{-1} for total ammonia, (which relates to 19350 measurements taken during this period of research), is below the 95-percentile limit of 1.3mg l^{-1} for a class C watercourse, but is higher than the recorded mean of 0.11 mg l^{-1} identified by the monthly GQA monitoring results for the same period. The maximum figure of 1.7mg l^{-1} would exceed the benchmark limit (1.3 mg l^{-1}) as identified for this research in Chapter 4. The mean values obtained for all of the parameters identified in Table 7.6, and in all three phases of this research, exceed the mean values for the corresponding period and parameter given in the respective Environment Agency Water Quality reports (Environment Agency, 1997, 2000 and

2003). The difference is possibly due to the improved accuracy of monitoring methods and is discussed further in Section 7.4.4.

7.3.2 Conclusions - featured investigations

During the pre-remediation phase there was a slight improvement in general water quality, arising from improved maintenance of the Albany Road structures during the period when the Consents to discharge were being reviewed by the Environment Agency (Section 3.2). This improvement continued through the post-remediation phase, assisted by the decline in manufacturing industry, and proactive pollution prevention campaigns in Coventry, and the adoption of environmental management systems by most of the major vehicle manufacturers and their suppliers. The latest situation has been evaluated further, by monitoring of the River Sherbourne culvert during a dry weather period in September 2003, followed by an investigation involving continuous monitoring and automated sampling, during wet weather in November 2003. The results of these investigations are discussed fully in Sections 7.2.2 and 7.2.3. In this section the findings will be compared to those of previous investigations, to identify any further improvements following remediation of the Albany Road problem, and the removal of the illegal or intermittent discharges identified in Phase 1 of this research. More recent continuous monitoring has not been possible following a review of monitoring resources in the area, and reprioritisation of workloads, by the Environment Agency.

a) Storm event, March 2001 (Auto 10)

The results for the storm event on 15 to 17 March 2001 were analysed for significance by undertaking a paired correlation using Spearman's rank correlation, to 95% and 99% confidence levels. A summary of the results is given in Table 7.7a) (highly significant results) and Table 7.7b) (significant results), detailing the rank correlation between the upstream and downstream sites and the specific parameters determined. The results

showed a high degree of consistency between the upstream and downstream sites during the storm event in the results obtained.

As detailed in Section 2.3, it was expected that ammonia levels would rise, and DO saturation would fall, during a storm as BOD increased showing a 'first flush ' effect of organic load on the watercourse (Section 2.2.1). On 15 – 17 March 2001 however, oxygen levels at both the upstream and downstream sites increased against flow significantly ($p< 0.01$), and ammonia decreased within the same confidence level ($p< 0.01$). The results demonstrate that during this event, previously identified problems relating to ammonia toxicity and oxygen depletion, may have been reduced by the remedial works subsequently undertaken to remove storm-related intermittent pollution sources. BOD showed no significant correlation with flow, but with solids, chloride and the heavy metals, a highly significant correlation ($p<0.01$) was identified, possibly pointing to particulate association for these determinands (Section 2.2.3). This is reflected in the highly significant ($p< 0.01$) correlation between SS and the heavy metals and BOD and the significant ($p< 0.05$) negative correlation with dissolved solids (TDS). The correlation with SS was only significant to 95% confidence levels for Chloride, and not significant for total P ($p=0.244$).

Total P showed significant correlation with the results for BOD and Cd, with no relationship identified for any other determinand. As with previous investigations, pH levels fell during storm events and were a reliable indicator of increased river levels showing a highly significant ($p< 0.01$) negative correlation (-0.808) between continuously measured pH at both sites and river flow. The relationship between auto-sampled pH and river flow was less significant ($p= 0.15$), and probably reflects the composite nature of the hourly spot samples against the dynamic 15-minute assessments, measured for flow and pH, by the continuous monitors.

Table 7.7a) March 2001 storm event Spearman's rank correlations (highly significant results p<0.01)

Key to table: red = negative correlation, black = positive correlation. US = upstream of city; DS = downstream of city

March 2001 storm highly sig.1	BOD	TON	SS	Total P	Sample pH	Tot Cd	Tot Cr	Tot Cu	Tot Zn	Tot Pb	Cl	RAIN
BOD 5 (Atu) mg l-1		-0.519	0.542		-0.731	0.613	0.581	0.817	0.772	0.668	0.438	
Total Oxidised Nitrogen mg l-1	-0.519		-0.693		-0.799	-0.579	-0.789	-0.674	-0.756	-0.86	-0.369	
Suspended Solids mg l-1	0.542	-0.693			-0.733	0.578	0.792	0.617	0.686	0.79		
Total Phosphate mg l-1						0.461						
Sampled pH (pH units)	-0.731	0.799	-0.733			-0.69	-0.774	-0.748	-0.801	-0.866	-0.464	
Total Cadmium µg l-1	0.613	-0.579	0.578	0.461	-0.69		0.737	0.615	0.679	0.719		0.37
Total Cr µg l-1	0.581	-0.789	0.792		-0.774	0.737		0.732	0.833	0.935	0.42	
Total Cu µg l-1	0.817	-0.674	0.617		-0.748	0.615	0.732		0.96	0.856	0.538	0.428
Total Zn µg l-1	0.772	-0.756	0.686		-0.801	0.679	0.833	0.96		0.922	0.561	0.471
Total Pb µg l-1	0.668	-0.86	0.79		-0.866	0.719	0.935	0.856	0.922		0.466	0.406
Chloride mg l-1Cl	0.438	-0.369			-0.464		0.42	0.538	0.561	0.466		
Rainfall mm						0.37		0.428	0.471	0.406		
DS Continuous DO % sat.	0.501											
DS Continuous NH3N mg l-1											0.44	
DS Continuous pH (pH units)		0.569	-0.514		0.38	-0.434	-0.517			-0.453		
DS Total Dissolved Solids g l-1												
DS Temperature Degrees C	-0.622			-0.405				-0.407				
River Depth (cm)		-0.421										
River Velocity (ms-1)		-0.588	0.501		-0.377	0.384	0.514			0.448		
River Flow (m3s-1)		-0.548	0.409				0.427			0.384		
US Continuous DO % sat.		0.579					-0.394			-0.382		
US Continuous NH3N mg l-1				0.389							-0.369	
US Continuous pH (pH units)		0.631	-0.508		0.45	-0.445	-0.53			-0.494		
US Total Dissolved Solids g l-1		-0.41					0.393					
US Temperature Degrees C		0.535	-0.434				-0.457			-0.383		

Table 7.7a) March 2001 storm event Spearman's rank correlations (highly significant results p<0.01)

Key to table: red = negative correlation, black = positive correlation. US = upstream of city; DS = downstream of city

March 2001 storm highly sig.2	DS DO%	DS NH3N	DS pH	DS TDS	DS Temp	US DO%	US NH3N	US pH	US TDS	US Temp	DEPTH	VELOCITY	FLOW
BOD 5 (Atu) mg l-1	0.501				-0.622								
Total Oxidised Nitrogen mg l-1			0.569			0.579		0.631	-0.41	0.535	-0.421	-0.588	-0.548
Suspended Solids mg l-1			-0.514					-0.508		-0.434		0.501	0.409
Total Phosphate mg l-1					-0.405		0.389						
Sampled pH (pH units)			0.38					0.45				-0.377	
Total Cadmium µg l-1			-0.434					-0.445				0.384	
Total Cr µg l-1			-0.517			-0.394		-0.53	0.393	-0.457		0.514	0.427
Total Cu µg l-1					-0.407								
Total Zn µg l-1													
Total Pb µg l-1			-0.453			-0.382		-0.494		-0.383		0.448	0.384
Chloride mg l-1Cl		0.44					-0.369						
Rainfall mm													
DS Continuous DO % sat.		-0.605	-0.26	-0.47	-0.824	0.872	-0.389	-0.36	-0.635	-0.612	0.492	0.295	0.5
DS Continuous NH3N mg l-1	-0.605		0.273	0.299	0.688	-0.378	0.439	0.411	0.378	0.696	-0.42	-0.604	-0.554
DS Continuous pH (pH units)	-0.26	0.273		-0.258	0.354	-0.227	0.406	0.896		0.626	-0.864	-0.392	-0.808
DS Total Dissolved Solids g l-1	-0.47	0.299	-0.258		0.536	-0.384			0.79	0.27		-0.334	
DS Temperature Degrees C	-0.824	0.688	0.354	0.536		-0.629	0.463	0.547	0.766	0.87	-0.537	-0.677	-0.695
River Depth (cm)	0.492	-0.42	-0.864		-0.537	0.35	-0.403	-0.886	-0.19	-0.735		0.464	0.918
River Velocity (ms-1)	0.295	-0.604	-0.392	-0.334	-0.677		-0.345	-0.596	-0.479	-0.837	0.464		0.728
River Flow (m3s-1)	0.5	-0.554	-0.808		-0.695	0.295	-0.472	-0.911	-0.368	-0.897	0.918	0.728	
US Continuous DO % sat.	0.872	-0.378	-0.227	-0.384	-0.629		-0.417	-0.228	-0.522	-0.379	0.35		0.295
US Continuous NH3N mg l-1	-0.389	0.439	0.406		0.463	-0.417		0.301	0.294	0.54	-0.403	-0.345	-0.472
US Continuous pH (pH units)	-0.36	0.411	0.896		0.547	-0.228	0.301		0.215	0.795	-0.886	-0.596	-0.911
US Total Dissolved Solids g l-1	-0.635	0.378		0.79	0.766	-0.522	0.294	0.215		0.575	-0.19	-0.479	-0.368
US Temperature Degrees C	-0.612	0.696	0.626	0.27	0.87	-0.379	0.54	0.795	0.575		-0.735	-0.837	-0.897

Table 7.7b) March 2001 storm event Spearman's rank correlations (Significant results p<0.05)

Key to table: red = negative correlation, black = positive correlation. US = upstream of city; DS = downstream of city

March 2001 storm significant	BOD ATU	TON	SS	Total P	Sample pH	Tot Cd	Tot Cr	Tot Cu	Tot Zn	Tot Pb	CHLORIDE	RAINFALL	US cont NH3N
BOD 5 (Atu) mg l-1				0.325								0.318	
Total Oxidised Nitrogen mg l-1												-0.339	
Suspended Solids mg l-1											0.331		
Total Phosphate mg l-1	0.325												
Sampled pH (pH units)												-0.294	
Total Cadmium µg l-1											0.365		
Total Cr µg l-1												0.345	
Total Cu µg l-1													
Total Zn µg l-1													
Total Pb µg l-1													
Chloride mg l-1Cl			0.331										
Rainfall mm	-0.318	-0.339					0.345						0.36
DS Continuous DO % sat.								0.36			0.353		
DS Total Dissolved Solids g l-1	-0.312										-0.289		
DS Temperature Degrees C									-0.325				
River Depth (cm)					-0.293	0.317	0.332						
River Flow (m3s-1)					-0.348	0.339							
US Continuous DO % sat.			-0.346		-0.335	-0.362							
US Continuous NH3N mg l-1												0.36	
US Total Dissolved Solids g l-1			0.349		-0.297	0.368				0.33	-0.295		
US Temperature Degrees C					0.356	-0.363							

NB: all correlations between continuous monitor results and sites were Highly significant (see Table 6.5a) or showed no significance at all.

Highly significant negative correlations (-0.679 to -0.799), between auto-sampled pH levels and heavy metal concentrations at Humber Avenue, were repeated for continuously monitored pH (both sites), against heavy metal concentrations at Humber Avenue (-0.258 to -0.517), and at Meadow Street (-0.445 to –0.53), and the continuous pH measurements at the upstream and downstream site were well matched with the auto sample results ($p<0.01$). Lower correlation coefficients for the continuous monitoring reflected the greater number of readings taken during the storm event.

Metal concentrations increased during the storm event as the pH decreased. Levels were determined as total metals (not as dissolved metals) during the storm event, and any increased solubility of some metals in acid conditions (Johansson *et al.*, 1995; Kalbitz *et al.*, 1998) was not therefore, identified in this research. The highly significant correlations between SS and the heavy metals would suggest that the metals were particle bound. There was no significant correlation found between TDS and heavy metals at Humber Avenue. At Humber Avenue Total Cr showed a highly significant correlation with TDS at Meadow Street, which may be indicate that the initial soluble component possibly present upstream of the city culvert became absorbed onto particles during transportation (Hewitt and Rashed, 1992) along the watercourse, or deposited as sediment (Charlesworth, 2003). Without total and soluble metals analysis at both sites, it is not possible to explore this likelihood further and the mechanism for transportation of total Cr is not clear. The general trends as river depth increased during the March 2001 storm event can be summarised, as shown in Table 7.8. These trends were compared to previous results (Phase 1 and 2) and against trends identified in the September and November 2003 investigations (Tables 7.11 and 7.14) to consider (Chapter 8) a general water quality model for storm events in the River Sherbourne catchment.

Table 7.8. General trends for March 2001 storm event.

Key: ↑ increase ↓ decrease ◙ no trend identified

	depth	BOD	TON	SS	Total P	pH	Cd	Cr	Cu	Zn	Pb	Cl	Temp.	DO % satn	NH_4^+N	Cont. pH	TDS	flow	rainfall
US	◙	◙	◙	◙	◙	◙	◙	◙	◙	◙	◙	◙	◙	↑	↓	↓	↓	↑	↑
DS	↑	↑	↓	↑	↑	↓	↑	↑	↑	↑	↑	↑	↓	↑	↓	↓	↑	↑	↑

b) Dry weather investigation September 2003 and November 2003 storm event

During the dry weather run during September 2003, the results were relatively stable, with little variation throughout the monitoring period, as detailed in Section 7.2.2. Where small peaks did arise, such as for SS and heavy metals, it was possible to identify where relationships between the concentrations of the different parameters were demonstrated under dry weather conditions. The rank correlation identified during the September dryweather investigation, against upstream and downstream river levels, during dryweather are shown in Table 7.9 (highly significant results, $p>0.01$) and Table 7.10) (significant results, $p> 0.05$) and summarised in Table 7.11.

Table 7.9 September 2003 Dry weather highly significant results (p>0.01) using Spearman's rank

Dryweather Highly Significant1	US BOD ATU	DS BOD ATU	DS BOD ATU+1	US C - Org Filt	DS C - Org Filt	DS C - Org Filt+1	US COD	DS COD	DS COD+1	US Cu	US Pb	DS TON	DS TON+1	US pH sam	DS pH sam	DS pH sam+1	US SS	DS SS
US BOD ATU mgl-1		0.797		0.795			0.765			0.951		-0.775						
DS BOD ATU mgl-1	0.797			0.894	0.724		0.766			0.735								
DS BOD ATU mgl-1+1						0.724				0.74								
US C - Org Filt mgl-1	0.795	0.894					0.769			0.801						0.846		
DS C - Org Filt mgl-1		0.724					0.716										0.794	
DS C - Org Filt mgl-1+1			0.724															
US COD as O2 mgl-1	0.765	0.766		0.769	0.716					0.762								
DS COD as O2 mgl-1																		0.807
DS COD as O2 mgl-1+1																		
US Copper - Cu ugl-1	0.951	0.735	0.74	0.801			0.762					-0.804			0.808			
US Lead - as Pb ugl-1																		
DS N Oxidised mgl-1	-0.775									-0.804								
DS N Oxidised mgl-1+1															-0.751			
US pH (pH units)																		
DS pH (ph units)				0.846						0.808			-0.751			0.828		
DS pH (ph units) +1					0.794										0.828			
DS Sld Sus@105C mgl-1								0.807										
DS Sld Sus@105C mgl-1+1									0.807									
US Zinc - as Zn ugl-1							0.716				0.741							
DS Zinc - as Zn ugl-1							-0.726											
DS Zinc - as Zn ugl-1+1																		
Flow US	0.758		0.826	0.781			0.719			0.888			-0.724		0.926	0.818		
flowus+.25	0.758		0.826	0.781			0.719			0.888			-0.724		0.926	0.818		
flowUS+.5	0.791		0.854	0.812			0.792			0.905					0.913	0.804		
level US	0.758		0.826	0.781			0.719			0.888			-0.724		0.926	0.818		
levelUS +.25	0.758		0.826	0.781			0.719			0.888			-0.724		0.928	0.818		
levelUS+.5	0.791		0.854	0.812			0.792			0.905					0.913	0.804		
level DS														-0.765	-0.86			
levelDS-.25																		
levelDS-.5																		
levelDS-.75																		
levelDS-1.0																		
US cont Temp degC			0.84	0.717						0.715				0.718	0.858	0.858		
DS cont Temp degC	0.779	0.851	0.858	0.892			0.753			0.86					0.857	0.857		
DS cont Temp degC +1		0.763	0.851	0.801						0.776				0.74	0.857	0.857		
DS cont Temp degC +2			0.763											0.794		0.857		
US cont SpCond mScm-1															0.785			
DS cont SpCond mScm-1		0.749		0.758			0.716			0.713					0.759			
DS cont SpCond mScm-1+1	0.789	0.907	0.749	0.903			0.762			0.783					0.71	0.759		
DS cont SpCond mScm-1+2	0.884	0.745	0.907	0.773			0.762			0.965	0.741	-0.825			0.857	0.71		
US cont DO %sat	0.779	0.851	0.823	0.892			0.753			0.86					0.857	0.857		
DS cont DO %sat	0.856						0.762			0.867		-0.727			0.71			
DS cont DO %sat+1	0.842			0.78			0.753			0.902			-0.727		0.857	0.71		
DS cont DO %sat+2	0.832	0.752		0.847						0.881					0.857	0.857		
US cont Ammonia mgl-1				0.827											0.837	1		
DS cont Ammonia mgl-1																		
DS cont Ammonia mgl-1 +1																		
DS cont Ammonia mgl-1+2																		
US cont pH (pH Units)			0.825							0.723				0.797	0.869	0.821		
DS cont pH (pH Units)	0.861						0.765			0.919		-0.723			0.811			
DS cont pH (pH Units)+1	0.819	0.769		0.871			0.737			0.874			-0.723		0.86	0.811		
DS cont pH (pH Units)+2	0.754	0.722	0.769	0.79						0.816				0.711	0.858	0.86		

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.9 September 2003 Dry weather highly significant results (p>0.01) using Spearman's rank

Dryweather Highly Significant2	DS SS+1	US Zn	DS Zn	DS Zn+1	Flow US	flowus+.25	flowUS+.5	level US	levelUS +.25	levelUS+.5	level DS	level DS-.25	level DS-.5	level DS-.75	level DS-1.0	US cont Temp	DS cont Temp
US BOD ATU mgl-1					0.758	0.758	0.791	0.758	0.758	0.791							0.779
DS BOD ATU mgl-1																	0.851
DS BOD ATU mgl-1+1					0.826	0.826	0.854	0.826	0.826	0.854						0.84	0.858
US C - Org Filt mgl-1					0.781	0.781	0.812	0.781	0.781	0.812						0.717	0.892
DS C - Org Filt mgl-1																	
DS C - Org Filt mgl-1+1																	
US COD as O2 mgl-1		0.716	-0.726		0.719	0.719	0.792	0.719	0.719	0.792							0.753
DS COD as O2 mgl-1																	
DS COD as O2 mgl-1+1	0.807																
US Copper - Cu ugl-1					0.888	0.888	0.905	0.888	0.888	0.905						0.715	0.86
US Lead - as Pb ugl-1		0.741															
DS N Oxidised mgl-1																	
DS N Oxidised mgl-1+1					-0.724	-0.724		-0.724	-0.724								
US pH (pH units)											-0.765					0.718	
DS pH (ph units)					0.926	0.926	0.913	0.926	0.926	0.913	-0.86					0.858	0.857
DS pH (ph units) +1					0.818	0.818	0.804	0.818	0.818	0.804						0.858	0.857
DS Sld Sus@105C mgl-1																	
DS Sld Sus@105C mgl-1+1																	
US Zinc - as Zn ugl-1																	
DS Zinc - as Zn ugl-1							-0.722										
DS Zinc - as Zn ugl-1+1																	
Flow US						0.962	0.928	1	0.962	0.928						0.861	0.933
flowus+.25					0.962		0.962	0.962	1	0.962						0.869	0.931
flowUS+.5					0.928	0.962		0.928	0.962	1	-0.385					0.874	0.931
level US					1	0.962	0.928		0.962	0.928						0.861	0.933
levelUS +.25					0.962	1	0.962	0.962		0.962						0.869	0.931
levelUS+.5			-0.722		0.928	0.962	1	0.928	0.962		-0.385					0.874	0.931
level DS							-0.385			-0.385		0.878	0.743	0.625	0.506	-0.394	
levelDS-.25											0.878		0.881	0.747	0.633		
levelDS-.5											0.743	0.881		0.883	0.751		
levelDS-.75											0.625	0.747	0.883		0.885		
levelDS-1.0											0.506	0.633	0.751	0.885			
US cont Temp degC					0.861	0.869	0.874	0.861	0.869	0.874	-0.394						0.954
DS cont Temp degC					0.933	0.931	0.931	0.933	0.931	0.931						0.954	
DS cont Temp degC +1					0.879	0.887	0.897	0.879	0.887	0.897	-0.369					0.989	0.974
DS cont Temp degC +2					0.538	0.538	0.537	0.538	0.538	0.537						0.825	0.625
US cont SpCond mScm-1					0.448	0.477	0.493	0.448	0.477	0.493	-0.642	-0.509	-0.409			0.504	0.467
DS cont SpCond mScm-1					0.552	0.565	0.615	0.552	0.565	0.615	-0.611	-0.533	-0.168	-0.401		0.499	0.574
DS cont SpCond mScm-1+1					0.86	0.865	0.884	0.86	0.865	0.884						0.827	0.888
DS cont SpCond mScm-1+2					0.853	0.887	0.908	0.853	0.887	0.908	-0.432	-0.397				0.843	0.899
US cont DO %sat					0.898	0.908	0.921	0.898	0.908	0.921	-0.414					0.929	0.979
DS cont DO %sat			-0.757	-0.729	0.743	0.737	0.723	0.743	0.737	0.723	-0.437	-0.494	-0.524	-0.536	-0.537	0.611	0.677
DS cont DO %sat+1			-0.732	-0.757	0.85	0.875	0.891	0.85	0.875	0.891	-0.531	-0.533	-0.522	-0.504	-0.48	0.763	0.817
DS cont DO %sat+2				-0.732	0.829	0.854	0.878	0.829	0.854	0.878	-0.563	-0.542	-0.512	-0.468	-0.419	0.899	0.889
US cont Ammonia mgl-1					0.778	0.798	0.821	0.778	0.798	0.821	-0.49	-0.401				0.845	0.845
DS cont Ammonia mgl-1											-0.513	-0.413					
DS cont Ammonia mgl-1 +1																	
DS cont Ammonia mgl-1+2														0.434	0.49		
US cont pH (pH Units)					0.832	0.837	0.848	0.832	0.837	0.848	-0.455	-0.378				0.971	0.923
DS cont pH (pH Units)			-0.733	-0.72	0.825	0.826	0.818	0.825	0.826	0.818	-0.496	-0.54	-0.549	-0.551	-0.518	0.698	0.757
DS cont pH (pH Units)+1				-0.733	0.843	0.87	0.897	0.843	0.87	0.897	-0.543	-0.514	-0.5	-0.487	-0.455	0.85	0.872
DS cont pH (pH Units)+2					0.799	0.822	0.845	0.799	0.822	0.845	-0.595	-0.564	-0.494	-0.418		0.921	0.89

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.9 September 2003 Dry weather highly significant results (p>0.01) using Spearman's rank

Dryweather Highly Significant3	DS cont Temp+1	DS cont Temp+2	US cont SC	DS cont SC	DS cont SC+1	DS cont SC+2	US cont DO	DS cont DO	DS cont DO+1	DS cont DO+2
US BOD ATU mgl-1					0.789	0.884	0.779	0.856	0.842	0.832
DS BOD ATU mgl-1	0.763			0.749	0.907	0.745	0.851			0.752
DS BOD ATU mgl-1+1	0.851	0.763			0.749	0.907	0.823			
US C - Org Filt mgl-1	0.801			0.758	0.903	0.773	0.892		0.78	0.847
DS C - Org Filt mgl-1										
DS C - Org Filt mgl-1+1										
US COD as O2 mgl-1				0.716	0.762	0.762	0.753	0.762	0.753	
DS COD as O2 mgl-1										
DS COD as O2 mgl-1+1										
US Copper - Cu ugl-1	0.776			0.713	0.783	0.965	0.86	0.867	0.902	0.881
US Lead - as Pb ugl-1										
DS N Oxidised mgl-1						-0.825		-0.727		
DS N Oxidised mgl-1+1									-0.727	
US pH (pH units)	0.74	0.794								
DS pH (ph units)	0.857		0.785	0.759	0.71	0.857	0.857	0.71	0.857	0.857
DS pH (ph units) +1	0.857	0.857			0.759	0.71	0.857		0.71	0.857
DS Sld Sus@105C mgl-1										
DS Sld Sus@105C mgl-1+1										
US Zinc - as Zn ugl-1										
DS Zinc - as Zn ugl-1								-0.757	-0.732	
DS Zinc - as Zn ugl-1+1								-0.729	-0.757	-0.732
Flow US	0.879	0.538	0.448	0.552	0.86	0.853	0.898	0.743	0.85	0.829
flowus+.25	0.887	0.538	0.477	0.565	0.865	0.887	0.908	0.737	0.875	0.854
flowUS+.5	0.897	0.537	0.493	0.615	0.884	0.908	0.921	0.723	0.891	0.878
level US	0.879	0.538	0.488	0.552	0.86	0.853	0.898	0.743	0.85	0.829
levelUS +.25	0.887	0.538	0.477	0.565	0.865	0.887	0.908	0.737	0.875	0.854
levelUS+.5	0.897	0.537	0.493	0.615	0.884	0.908	0.921	0.723	0.891	0.878
level DS	-0.369	-0.44	-0.642	-0.611		-0.432	-0.414	-0.437	-0.531	-0.563
levelDS-.25			-0.509	-0.533		-0.397		-0.494	-0.533	-0.542
levelDS-.5			-0.409	-0.468				-0.524	-0.522	-0.512
levelDS-.75				-0.401				-0.536	-0.504	-0.468
levelDS-1.0								-0.537	-0.48	-0.419
US cont Temp degC	0.989	0.825	0.504	0.499	0.827	0.843	0.929	0.611	0.763	0.899
DS cont Temp degC	0.974	0.652	0.467	0.574	0.888	0.899	0.979	0.677	0.817	0.889
DS cont Temp degC +1		0.768	0.479	0.538	0.858	0.87	0.96	0.647	0.79	0.906
DS cont Temp degC +2	0.768		0.506		0.51	0.517	0.621		0.426	0.679
US cont SpCond mScm-1	0.479	0.506		0.536	0.405	0.452	0.505		0.492	0.481
DS cont SpCond mScm-1	0.538		0.536		0.571	0.575	0.644	0.744	0.788	0.659
DS cont SpCond mScm-1+1	0.858	0.51	0.405	0.571		0.851	0.86	0.72	0.826	0.855
DS cont SpCond mScm-1+2	0.87	0.517	0.452	0.575	0.851		0.898	0.726	0.846	0.879
US cont DO %sat	0.96	0.621	0.505	0.644	0.86	0.898		0.687	0.826	0.895
DS cont DO %sat	0.647			0.744	0.72	0.726	0.687		0.905	0.756
DS cont DO %sat+1	0.79	0.426	0.492	0.788	0.826	0.846	0.826	0.905		0.902
DS cont DO %sat+2	0.906	0.679	0.481	0.659	0.855	0.879	0.895	0.756	0.902	
US cont Ammonia mgl-1	0.843	0.698	0.558	0.469	0.758	0.764	0.844	0.434	0.718	0.844
DS cont Ammonia mgl-1		0.515	0.622							
DS cont Ammonia mgl-1 +1										
DS cont Ammonia mgl-1+2								-0.413		
US cont pH (pH Units)	0.971	0.835	0.541	0.514	0.799	0.824	0.92	0.621	0.756	0.882
DS cont pH (pH Units)	0.726		0.385	0.764	0.785	0.796	0.767	0.967	0.965	0.85
DS cont pH (pH Units)+1	0.866	0.555	0.51	0.733	0.847	0.875	0.873	0.827	0.966	0.962
DS cont pH (pH Units)+2	0.928	0.776	0.52	0.614	0.804	0.852	0.912	0.683	0.823	0.964

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.9 September 2003 Dry weather highly significant results (p>0.01) using Spearman's rank

Dryweather Highly Significant4	US cont NH3N	DS cont NH3N	DS cont NH3N+1	DS cont NH3N+2	US cont pH	DS cont pH	DS cont pH +1	DS cont pH +2		
US BOD ATU mgl-1						0.861	0.819	0.754		
DS BOD ATU mgl-1							0.769	0.722		
DS BOD ATU mgl-1+1					0.825			0.769		
US C - Org Filt mgl-1	0.827						0.871	0.79		
DS C - Org Filt mgl-1										
DS C - Org Filt mgl-1+1										
US COD as O2 mgl-1						0.765	0.737			
DS COD as O2 mgl-1										
DS COD as O2 mgl-1+1										
US Copper - Cu ugl-1					0.723	0.919	0.874	0.816		
US Lead - as Pb ugl-1										
DS N Oxidised mgl-1						-0.723				
DS N Oxidised mgl-1+1							-0.723			
US pH (pH units)								0.711		
DS pH (ph units)	0.837				0.869	0.811	0.86	0.858		
DS pH (ph units) +1	1				0.821		0.811	0.86		
DS Sld Sus@105C mgl-1										
DS Sld Sus@105C mgl-1+1										
US Zinc - as Zn ugl-1										
DS Zinc - as Zn ugl-1						-0.733				
DS Zinc - as Zn ugl-1+1						-0.72	-0.733			
Flow US	0.778				0.832	0.825	0.843	0.799		
flowus+.25	0.798				0.837	0.826	0.87	0.822		
flowUS+.5	0.821				0.848	0.818	0.897	0.845		
level US	0.778				0.832	0.826	0.843	0.799		
levelUS +.25	0.798				0.837	0.826	0.87	0.822		
levelUS+.5	0.821				0.848	0.818	0.897	0.845		
level DS	-0.49	-0.513			-0.455	-0.496	-0.543	-0.595		
levelDS-.25	-0.401	-0.413			-0.378	-0.54	-0.514	-0.564		
levelDS-.5						-0.549	-0.5	-0.494		
levelDS-.75				0.434		-0.551	-0.487	-0.418		
levelDS-1.0				0.49		-0.518	-0.455			
US cont Temp degC	0.845				0.971	0.698	0.85	0.921		
DS cont Temp degC	0.845				0.923	0.757	0.872	0.89		
DS cont Temp degC +1	0.843				0.971	0.726	0.866	0.928		
DS cont Temp degC +2	0.698	0.515			0.835		0.555	0.776		
US cont SpCond mScm-1	0.558	0.622			0.541	0.385	0.51	0.52		
DS cont SpCond mScm-1	0.469				0.514	0.764	0.733	0.614		
DS cont SpCond mScm-1+1	0.758				0.799	0.785	0.847	0.804		
DS cont SpCond mScm-1+2	0.764				0.824	0.796	0.875	0.852		
US cont DO %sat	0.844				0.92	0.767	0.873	0.912		
DS cont DO %sat	0.434			-0.413	0.621	0.967	0.827	0.683		
DS cont DO %sat+1	0.718				0.756	0.965	0.966	0.823		
DS cont DO %sat+2	0.844				0.882	0.85	0.962	0.964		
US cont Ammonia mgl-1		0.529	0.465		0.832	0.587	0.815	0.849		
DS cont Ammonia mgl-1	0.529		0.576		0.367					
DS cont Ammonia mgl-1 +1	0.465	0.576		0.518						
DS cont Ammonia mgl-1+2			0.518							
US cont pH (pH Units)	0.832	0.367				0.695	0.829	0.938		
DS cont pH (pH Units)	0.587				0.695		0.903	0.771		
DS cont pH (pH Units)+1	0.815				0.829	0.903		0.895		
DS cont pH (pH Units)+2	0.849				0.938	0.771	0.895			

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.10 September 2003 Dry weather significant results (p>0.05) using Spearman's rank

Dryweather significant 1	US BOD ATU	DS BOD ATU	DS BOD ATU+1	US C - Org Filt	DS C - Org Filt	DS C - Org Filt+1	US Cr	DS-Cr	DS -Cr+1	US COD	DS COD	DS COD+1	US Cu	DS Cu	DSCu+1	US Pb	DS Pb	DS Pb+1	US TON	DS TON
US BOD ATU mgl-1			0.642																	
DS BOD ATU mgl-1						0.673														-0.682
DS BOD ATU mgl-1+1	0.642									0.677										-0.626
US C - Org Filt mgl-1					0.582									0.613						
DS C - Org Filt mgl-1				0.582		0.609					0.598									
DS C - Org Filt mgl-1+1		0.673			0.609					0.674										
US Chromium -Cr ugl-1								0.649									0.595			
DS Chromium -Cr ugl-1							0.649													
DS Chromium -Cr ugl-1+1																				
US COD as O2 mgl-1			0.677			0.674									0.674					-0.643
DS COD as O2 mgl-1					0.598															
DS COD as O2 mgl-1+1						0.598														
US Copper - Cu ugl-1																				
DS Copper - Cu ugl-1				0.613																
DS Copper - Cu ugl-1+1		0.618								0.674										
US Lead - as Pb ugl-1																			-0.67	
DS Lead - as Pb ugl-1							0.595													
DS Lead - as Pb ugl-1+1																				
US N Oxidised mgl-1																-0.67				
DS N Oxidised mgl-1		-0.682	-0.682							-0.643										
DS N Oxidised mgl-1+1			-0.682																	
US pH (pH units)			0.632			0.608										-0.664				
DS pH (ph units)	0.639		0.725	0.667																
DS pH (ph units) +1													0.657							
US Sld Sus@105C mgl-1	0.608	0.652	0.612							0.604	0.621			0.67						
DS Sld Sus@105C mgl-1																				
DS Sld Sus@105C mgl-1+1							0.731													
US Zinc - as Zn ugl-1	0.653				0.671														-0.581	-0.615
DS Zinc - as Zn ugl-1											-0.607									
DS Zinc - as Zn ugl-1+1	-0.691											-0.607	-0.606							
Flow US		0.665																		-0.62
flowus+.25		0.665																		-0.62
flowUS+.5		0.708																		-0.685
level US		0.665																		-0.62
levelUS +.25		0.665																		-0.62
levelUS+.5		0.708																		-0.685
level DS													-0.579							
levelDS-.25													-0.582					-0.614		
levelDS-.5													-0.606					-0.602		
levelDS-.75	-0.588												-0.611					-0.58		
levelDS-1.0	-0.646												-0.653							
US cont Temp degC	0.61	0.66													0.611					
DS cont Temp degC					0.601	0.608								0.599	0.606					-0.657
DS cont Temp degC +1	0.691					0.601				0.597					0.599					-0.594
DS cont Temp degC +2																-0.65				
US cont SpCond mScm-1				0.576					0.581				0.651							
DS cont SpCond mScm-1	0.6				0.699									0.644						-0.587
DS cont SpCond mScm-1+1						0.699									0.644					
DS cont SpCond mScm-1+2																				
US cont DO %sat					0.594										0.592					-0.706
DS cont DO %sat		0.675	0.664	0.631		0.587						0.621								
DS cont DO %sat+1		0.689	0.675																	-0.608
DS cont DO %sat+2		0.752	0.889							0.661										-0.615
US cont Ammonia mgl-1		0.618											0.666							
DS cont Ammonia mgl-1																-0.666			0.679	
DS cont Ammonia mgl-1 +1																				
DS cont Ammonia mgl-1+2																				
US cont pH (pH Units)	0.619	0.663		0.662																-0.645
DS cont pH (pH Units)		0.658	0.68	0.692																
DS cont pH (pH Units)+1			0.658																	
DS cont pH (pH Units)+2																				-0.595

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.10 September 2003 Dry weather significant results (p>0.05) using Spearman's rank

Dryweather significant 2	DS TON+1	US pH sam	DS pH sam	DS pH sam+1	US SS	DS SS	DS SS+1	US Zn	DS Zn	DS Zn+1	Flow US	flowus+.25	flowUS+.5	level US	levelUS +.25	levelUS+.5	level DS	level DS-.25	level DS-.5	level DS-.75	level DS-1.0
US BOD ATU mgl-1			0.639		0.608			0.653		-0.691										-0.588	-0.646
DS BOD ATU mgl-1					0.652						0.665	0.665	0.708	0.665	0.665	0.708					
DS BOD ATU mgl-1+1	-0.682	0.632	0.725		0.612																
US C - Org Filt mgl-1			0.667																		
DS C - Org Filt mgl-1																					
DS C - Org Filt mgl-1+1		0.608																			
US Chromium -Cr ugl-1							0.731														
DS Chromium -Cr ugl-1																					
DS Chromium -Cr ugl-1+1																					
US COD as O2 mgl-1					0.604																
DS COD as O2 mgl-1					0.621				-0.607												
DS COD as O2 mgl-1+1										-0.607											
US Copper - Cu ugl-1				0.657						-0.606							-0.579	-0.582	-0.606	-0.611	-0.653
DS Copper - Cu ugl-1					0.67																
DS Copper - Cu ugl-1+1																					
US Lead - as Pb ugl-1		-0.664																			
DS Lead - as Pb ugl-1																					
DS Lead - as Pb ugl-1+1																		-0.614	-0.602	-0.58	
US N Oxidised mgl-1								-0.581													
DS N Oxidised mgl-1								-0.615			-0.62	-0.62	-0.685	-0.62	-0.62	-0.685					
DS N Oxidised mgl-1+1									0.72				-0.689			-0.689					
US pH (pH units)																					
DS pH (ph units)																					
DS pH (ph units)+1																					
US Sld Sus@105C mgl-1						0.606		0.669													
DS Sld Sus@105C mgl-1					0.606																
DS Sld Sus@105C mgl-1+1																					
US Zinc - as Zn ugl-1					0.669																
DS Zinc - as Zn ugl-1	0.72										-0.628	-0.628		-0.628	-0.628						
DS Zinc - as Zn ugl-1+1											-0.593	-0.593	-0.64	-0.593	-0.593	-0.64					
Flow US									-0.628	-0.593							-0.327	-0.283			
flowus+.25									-0.628	-0.593							-0.358	-0.31			
flowUS+.5	-0.689									-0.64								-0.332			
level US									-0.628	-0.593							-0.327	-0.283			
levelUS +.25									-0.628	-0.593							-0.358	-0.31			
levelUS+.5	-0.689									-0.64								-0.332			
level DS											-0.327	-0.358		-0.327	-0.358						
levelDS-.25											-0.283	-0.31	-0.332	-0.283	-0.31	-0.332					
levelDS-.5																					
levelDS-.75																					
levelDS-1.0																					
US cont Temp degC	-0.641									-0.612								-0.322			
DS cont Temp degC	-0.685				0.585				-0.627	-0.62							-0.328				
DS cont Temp degC +1	-0.657								-0.595	-0.627								-0.298			
DS cont Temp degC +2	-0.594		0.612							-0.595								-0.362			
US cont SpCond mScm-1		0.625																		-0.31	
DS cont SpCond mScm-1	-0.678				0.585				-0.673												-0.363
DS cont SpCond mScm-1+1	-0.587								-0.606	-0.673							-0.292				
DS cont SpCond mScm-1+2									-0.595	-0.606									-0.356	-0.343	
US cont DO %sat	-0.671	0.601							-0.627									-0.339			
DS cont DO %sat																					
DS cont DO %sat+1																					
DS cont DO %sat+2	-0.608	0.58							-0.595												
US cont Ammonia mgl-1																			-0.312		
DS cont Ammonia mgl-1			0.598	0.598				-0.615			0.297	0.313	0.328	0.297	0.313	0.328			-0.301		
DS cont Ammonia mgl-1 +1				0.598		-0.621															
DS cont Ammonia mgl-1+2							-0.621												0.346		
US cont pH (pH Units)	-0.64																		-0.318		
DS cont pH (pH Units)	-0.633																				
DS cont pH (pH Units)+1									-0.694												
DS cont pH (pH Units)+2										-0.694											-0.343

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.10 September 2003 Dry weather significant results (p>0.05) using Spearman's rank

Dryweather significant 3	US cont Temp	DS cont Temp	DS cont Temp+	DS cont Temp+2	US cont SC	DS cont SC	DS cont SC+1	DS cont SC+2	US cont DO	DS cont DO	DS cont DO+1	DS cont DO+	US cont NH3N	DS cont NH3N	
US BOD ATU mgl-1	0.61		0.691			0.6									
DS BOD ATU mgl-1	0.66									0.675	0.689		0.618		
DS BOD ATU mgl-1+1										0.664	0.675	0.689			
US C - Org Filt mgl-1					0.576					0.631					
DS C - Org Filt mgl-1		0.601				0.699			0.594						
DS C - Org Filt mgl-1+1		0.608	0.601				0.699			0.587					
US Chromium -Cr ugl-1															
DS Chromium -Cr ugl-1															
DS Chromium -Cr ugl-1+1					0.581										
US COD as O2 mgl-1			0.597									0.661			
DS COD as O2 mgl-1															
DS COD as O2 mgl-1+1															
US Copper - Cu ugl-1					0.651								0.666		
DS Copper - Cu ugl-1		0.599				0.644									
DS Copper - Cu ugl-1+1	0.611	0.606	0.599				0.644		0.592						
US Lead - as Pb ugl-1				-0.65										-0.666	
DS Lead - as Pb ugl-1															
DS Lead - as Pb ugl-1+1															
US N Oxidised mgl-1														0.679	
DS N Oxidised mgl-1		-0.657	-0.594			-0.587			-0.706		-0.608	-0.615			
DS N Oxidised mgl-1+1	-0.641	-0.685	-0.657	-0.594		-0.678	-0.587		-0.671			-0.608			
US pH (pH units)					0.625				0.601			0.58			
DS pH (ph units)				0.612										0.598	
DS pH (ph units) +1														0.598	
US Sld Sus@105C mgl-1		0.585				0.585		0.627							
DS Sld Sus@105C mgl-1															
DS Sld Sus@105C mgl-1+1															
US Zinc - as Zn ugl-1														-0.615	
DS Zinc - as Zn ugl-1		-0.627	-0.595			-0.673	-0.606	-0.595	-0.627			-0.595			
DS Zinc - as Zn ugl-1+1	-0.612	-0.62	-0.627	-0.595			-0.673	-0.606							
Flow US														0.297	
flowus+.25														0.313	
flowUS+.5														0.328	
level US														0.297	
levelUS +.25														0.313	
levelUS+.5														0.328	
level DS		-0.328					-0.292								
levelDS-.25	-0.322		-0.298	-0.362					-0.339						
levelDS-.5								-0.356					-0.312	-0.301	
levelDS-.75					-0.31			-0.343							
levelDS-1.0						-0.363									
US cont Temp degC														0.31	
DS cont Temp degC															
DS cont Temp degC +1															
DS cont Temp degC +2															
US cont SpCond mScm-1										0.314					
DS cont SpCond mScm-1															
DS cont SpCond mScm-1+1															
DS cont SpCond mScm-1+2															
US cont DO %sat															
DS cont DO %sat					0.314										
DS cont DO %sat+1															
DS cont DO %sat+2															
US cont Ammonia mgl-1															
DS cont Ammonia mgl-1		0.31													
DS cont Ammonia mgl-1 +1					0.285					-0.346					
DS cont Ammonia mgl-1+2															
US cont pH (pH Units)															
DS cont pH (pH Units)				0.363											
DS cont pH (pH Units)+1															
DS cont pH (pH Units)+2														0.349	

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.10 September 2003 Dry weather significant results (p>0.05) using Spearman's rank

Dry weather significant 4	DS cont NH3N+1	DS cont NH3N+2	US cont pH	DS cont pH	DS cont pH +1	DS cont pH +2
US BOD ATU mgl-1			0.619			
DS BOD ATU mgl-1			0.663	0.658		
DS BOD ATU mgl-1+1				0.68	0.558	
US C - Org Filt mgl-1			0.662	0.692		
DS C - Org Filt mgl-1						
DS C - Org Filt mgl-1+1						
US Chromium -Cr ugl-1						
DS Chromium -Cr ugl-1						
DS Chromium -Cr ugl-1+1						
US COD as O2 mgl-1						
DS COD as O2 mgl-1						
DS COD as O2 mgl-1+1						
US Copper - Cu ugl-1						
DS Copper - Cu ugl-1						
DS Copper - Cu ugl-1+1						
US Lead - as Pb ugl-1						
DS Lead - as Pb ugl-1		-0.628				
DS Lead - as Pb ugl-1+1						
US N Oxidised mgl-1						
DS N Oxidised mgl-1			-0.645			-0.595
DS N Oxidised mgl-1+1			-0.64	-0.633		
US pH (pH units)						
DS pH (ph units)						
DS pH (ph units)+1	0.598					
US Sld Sus@105C mgl-1						
DS Sld Sus@105C mgl-1	-0.621					
DS Sld Sus@105C mgl-1+1		-0.621				
US Zinc - as Zn ugl-1						
DS Zinc - as Zn ugl-1					-0.694	
DS Zinc - as Zn ugl-1+1						-0.694
Flow US						
flowUs+.25						
flowUS+.5						
level US						
levelUS +.25						
levelUS+.5						
level DS						
levelDS-.25						
levelDS-.5		0.346	-0.318			
levelDS-.75						
levelDS-1.0						-0.343
US con: Temp degC						
DS con: Temp degC						
DS con: Temp degC +1						
DS con: Temp degC +2				0.363		
US con: SpCond mScm-1	0.285					
DS con: SpCond mScm-1						
DS con: SpCond mScm-1+1						
DS con: SpCond mScm-1+2						
US con: DO %sat						
DS con: DO %sat	-0.346					
DS con: DO %sat+1						
DS con: DO %sat+2						
US con: Ammonia mgl-1						
DS con: Ammonia mgl-1						0.349
DS con: Ammonia mgl-1 +1						
DS con: Ammonia mgl-1+2				-0.313		
US con: pH (pH Units)						
DS con: pH (pH Units)		-313				
DS con: pH (pH Units)+1						
DS con: pH (pH Units)+2						

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

During the dryweather run in September 2003, all parameters maintained constant levels, with a slight increase at the start of the run possibly due to disturbed solids during installation or the effects of a pre-investigation discharge. Readings for SC, temperature, Zn, Cu, Cr, SS and TON were higher at Humber Avenue downstream of the city, indicating some impact remaining from the culverted watercourses feeding to the River Sherbourne, with the possibility of misconnected sewerage systems or illegal trade effluent discharges. Concentrations for Pb and COD were the same at both sites as detailed in Section 7.2.2, and measurements for pH, BOD, COD and DO were higher at Meadow Street, upstream of the city. The river level at Kingsbury Avenue decreased very slightly from 86.662 m AOD, with no increases due to local inputs identified.

The slight decrease in depth over time allowed analysis of the data using Spearman's rank correlation test, to determine any significant (>0.05) or highly significant (>0.01) correlations between the parameters as shown in Table 7.9. This analysis allowed a series of trends to be identified for the dry weather events based only on significant and highly significant results. The overall trends at each monitoring site against river depth during the dryweather investigation, are summarised in Table 7.11:

Table 7.11 Trends during September dryweather investigation.
Key: ↑ increase ↓ decrease (highly significant) ◙ no correlation with other variables ↑↓ significant results

	depth	SS	BOD	C-org filter	COD	Cu	Pb	Zn	Cr	pH	TON	Spec. cond	DO % satn	Cont.NH_4^+	Cont. pH
US	↓	◙	↓	↓	↓	↓	◙	◙	◙	◙	◙	↓	↓	◙	↓
DS	↓	◙	◙	◙	◙	◙	◙	↑	◙	◙	◙	↓	↑	↓	↑
General trend If any	↓	◙	◙	◙	◙	◙	◙	◙	◙	◙	◙	↓	◙	◙	◙

The results for Pb, Zn, NH_4^+ N, SS and Cr all showed a marked decrease at the beginning of the investigation, and Zn concentration increased at Humber Avenue

during the monitoring period, contrary to the steady decrease in river depth The parameters that did not show any correlation with river level may still have showed a high correlation with each other, (such as Zn and Pb (highly significant at $p>0.01$) at Meadow Street), as shown in Table 7.9. The highly significant correlations ($p>0.01$) shown between Cu and the data for depth, BOD, filtered Organic C and COD, may indicate that the Cu was in soluble form, and associated with organic matter. No correlation with SS was identified, and no other metals demonstrated a relationship with BOD or filtered Organic-C.

During the dryweather monitoring period, sites at Meadow Street and Humber Avenue, upstream and downstream of the city centre, were sampled and monitored. These results can be compared to those obtained at both sites during a storm event in November 2003, as described in Section 7.2.3, although the continuous monitor during the November 2003 storm investigation failed at the downstream (Humber Avenue) site, due to storm debris causing blockage or damage to the monitor during the sampling run.

The relationships for the November storm, determined by rank correlation using the Spearman's test, are summarised in Table 7.12 (highly significant results, $p>0.01$) and Table 7.13 (significant results, $p> 0.05$), and key trends for the November storm are summarised in Table 7.14. These trends are compared to those identified for the March 2001 and September 2003 investigations in Table 7.15.

Table 7.12 November storm event 2003 highly significant rank correlations (Spearman's test) (p>0.01)

Nov storm highly significant 1	US BOD	DS BOD	DS BOD+1	US C-org F	DS C-org F	DS C org F+1	US Cd	DS Cd	DS Cd+1	US Cr	DS Cr	DS Cr+1	US COD	DS COD	DS COD+1	US Cu	DS Cu	DS Cu+1	US Pb	DS Pb	DS Pb+1
US BOD ATU mgl-1		.918**						.763**			.857**		.932**	.872**			.800**		.662**	.841**	
DS BOD ATU mgl-1	.918**							.830**			.921**		.863**	.977**			.916**			.965**	
DS BOD ATU mgl-1+1									.789**			.905**			.975**			.900**			.960**
US C - Org Filt mgl-1					.930**	.808**	.819**			.669**						.737**					
DS C - Org Filt mgl-1				.930**		.835**	.740**														
DS C - Org Filt mgl-1+1				.808**	.835**																
US Cadmium - Cd ugl-1				.819**	.740**					.815**						.862**					
DS Cadmium - Cd ugl-1	.763**	.830**								.662**	.899**		.727**	.762**			.822**			.800**	
DS Cadmium - Cd ugl-1+1			.789**									.879**			.708**			.782**			.755**
US Chromium -Cr ugl-1				.669**			.815**	.662**			0.722**					.941**	.708**				
DS Chromium -Cr ugl-1	.857**	.921**								.722**			.771**	.876**		.724**	.965**			.938**	
DS Chromium -Cr ugl-1+1			.905**						.879**						.845**			.956**			.923**
US COD as O2 mgl-1	.932**	.863**						.727**			.771**			.825**			.692**		.748**	.776**	
DS COD as O2 mgl-1	.872**	.977**						.762**			.876**		.825**				.902**			0.95	
DS COD as O2 mgl-1+1			.975**						.708**			.845**						.878**			0.938
US Copper - Cu ugl-1				.737**			.862**			0.941	0.724						.735**				
DS Copper - Cu ugl-1	.800**	.916**						.822**		.708**	.965**		.692**	.902**		.735**					
DS Copper - Cu ugl-1+1			.900**						.782**			.956**			.878**						0.956
US Lead - as Pb ugl-1	.662**												.748**								
DS Lead - as Pb ugl-1	.841**	.965**						.800**			.938**		.776**	.950**			.965**				
DS Lead - as Pb ugl-1+1			.960**						.755**			.923**			.938**			.956**			
US N Oxidised mgl-1																			.695**		.695**
DS N Oxidised mgl-1						.692**															
DS N Oxidised mgl-1+1						.709**							.692**								
US pH (pH units)	.733**									.794	.671**		.762**			.794**			.794**		
DS pH (ph units)	.798**	.796**						.808**			.866**		.735**	.694**			.776**			.804**	
DS pH (ph units) +1			.746**						.762**			.846**		.769**				.732		.705**	.768**
US Sld Sus@105C mgl-1	.718**												.812**								
DS Sld Sus@105C mgl-1	.861**	.951**						.771**			.829**		.881**	.946**			.837**			.925**	
DS Sld Sus@105C mgl-1+1			.944**						.719**			.791**			.938**			.802**			.912**
US Zinc - as Zn ugl-1				.851**			.938**			.871**	.692**					.911**	.701**				
DS Zinc - as Zn ugl-1	.879**	.929**						.862**		.761**	.978**		.758**	.889**		.748**	.969**			.938**	
DS Zinc - as Zn ugl-1+1			.916**						.832**			.973**			.861**			.962**			.923**
Rainfall						.700**															
Rainfall -1						-0.629															
Rainfall -2				.688**		-0.635															
Flow US						-0.648							.723**								
flowus+.25						.693**							.715**								
flowUS+.5						.713**							.689**						.687**		
level US						-0.648							.723**								
levelUS +.25						.693**							.715**								
levelUS+.5						.713**							.689**						.687**		
level DS						-0.674							.691**								
levelDS-.25						.692**							.692**								
levelDS-.5																					
levelDS-.75																					
levelDS-1.0																					
US cont Temp degC				.960**	.934**																
US cont SpCond mScm-1				.824**	.855**	.808**	.766**			.717**						.724**					
US cont DO %sat						.885**															
US cont Ammonia mgl-1																					
US cont pH (pH Units)																			-0.675		

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.12 November storm event 2003 highly significant rank correlations (Spearman's test) (p>0.01)

Nov storm highly significant 2	US TON	DS TON	DS TON +1	US pH	DS pH	DS pH +1	US SS	DS SS	DS SS+1	US Zn	DS Zn	DS Zn +1	Rainfall	Rainfall -1	Rainfall -2	Flow US	flowus+.25	flowUS+.5
US BOD ATU mgl-1				.733**	.798**		.718**	.861**			0.879							
DS BOD ATU mgl-1								.951**			0.929							
DS BOD ATU mgl-1+1						.746**			.944**			0.916						
US C - Org Filt mgl-1										.851**					-0.688			
DS C - Org Filt mgl-1										.780**								
DS C - Org Filt mgl-1+1		.692**	.709**										-0.7				.693**	.713**
US Cadmium - Cd ugl-1										.938**								
DS Cadmium - Cd ugl-1					.808**			.771**			0.862							
DS Cadmium - Cd ugl-1+1						.762**			.719**			0.832						
US Chromium -Cr ugl-1				.794**						.871**	0.761							
DS Chromium -Cr ugl-1				.671**	.866**			.829**		.692**	0.978							
DS Chromium -Cr ugl-1+1						.846**			.791**			0.973						
US COD as O2 mgl-1		.692**		.762**	.735**		.812**	.881**			0.758					0.723	.715**	.689**
DS COD as O2 mgl-1					.694**	.769**		.946**			0.889							
DS COD as O2 mgl-1+1									.938**			0.861						
US Copper - Cu ugl-1				.794**						.911**	0.748							
DS Copper - Cu ugl-1					.776**			.837**		.701**	0.969							
DS Copper - Cu ugl-1+1						.732**			.802**			0.962						
US Lead - as Pb ugl-1	.695**			.794**			.771**											.687**
DS Lead - as Pb ugl-1					.804**	.705**		.925**			0.938							
DS Lead - as Pb ugl-1+1						.768**			.912**			0.923						
US N Oxidised mgl-1		.873**	.725**		.733**		.794**									-0.842		
DS N Oxidised mgl-1	.873**		.940**				.893**	.714**						-0.74	-0.762	-0.96		
DS N Oxidised mgl-1+1	.725**	.940**					.812**	.731**					-0.703	-0.743	-0.827	-0.863	-0.902	-0.949
US pH (pH units)											-0.671							
DS pH (ph units)	.733**							.726**			-0.821							
DS pH (ph units) +1								.759**				-0.789						
US Sld Sus@105C mgl-1	.794**	.893**	.812**					.772**						0.709	0.747	0.869	.884**	.881**
DS Sld Sus@105C mgl-1		.714**	.731**		.726**	.759**	.772**				0.824					0.714	.693**	.682**
DS Sld Sus@105C mgl-1+1												0.786						
US Zinc - as Zn ugl-1											0.719							
DS Zinc - as Zn ugl-1				.671**	.821**	.644**		.824**		.719**								
DS Zinc - as Zn ugl-1+1						.789**			.786**									
Rainfall			.703**															
Rainfall -1		.740**	.743**				.709**									0.79	.803**	.791**
Rainfall -2		.762**	.827**				.747**									0.691	.747**	.758**
Flow US	.842**	.960**	.863**				.869**	.714**						0.79	0.691		.949**	.916**
flowus+.25	.823**	.961**	.902**				0.884	0.693						0.803	0.747	0.949		.951**
flowUS+.5	.777**	.950**	.949**				0.881	0.682						0.791	0.758	0.916	.951**	1.000**
level US	.842**	.960**	.863**				.869**	.714**						0.79	0.691	1	.949**	.916**
levelUS +.25	.823**	.961**	.902**				0.884	0.639						0.803	0.747	0.949	1.000**	.951**
levelUS+.5	.777**	.950**	.949**				.881**	.682**						0.791	0.758	0.916	.951**	1.000**
level DS	.858**	.990**	.916**		.672**		.874**	.739**						0.689	0.772	0.942	.936**	.923**
levelDS-.25	.873**	1.000**	.940**				.893**	.714**						0.74	0.762	0.935	.924**	.914**
levelDS-.5	.793**	.978**	.962**				.880**	.754**						0.711	0.813	0.924	.914**	.907**
levelDS-.75	.736**	.952**	.973**				.880**	.741**						0.722	0.804	0.914	.908**	.905**
levelDS-1.0	.701**	.921**	.989**				.851**	.705**						0.736	0.806	0.909	.905**	.902**
US cont Temp degC				-0.762												0.425	.440**	.424**
US cont SpCond mScm-1										0.842						-0.57	.572**	.559**
US cont DO %sat		.789**	.802**											0.675	0.797	0.777	.789**	.797**
US cont Ammonia mgl-1				-0.703												0.573	.573**	.568**
US cont pH (pH Units)	.873**	.911**	.877**				-0.887								-0.805	-0.864	.885**	.920**

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.12 November storm event 2003 highly significant rank correlations (Spearman's test) (p>0.01)

Nov storm highly significant 3	level US	levelUS +.25	levelUS+.5	level DS	levelDS-.25	levelDS-.5	levelDS-.75	levelDS-1.0	US cont Temp	US cont SC	US cont DO	US cont NH3N	US cont pH
US BOD ATU mgl-1													
DS BOD ATU mgl-1													
DS BOD ATU mgl-1+1													
US C - Org Filt mgl-1										.960**	.824**		
DS C - Org Filt mgl-1										.934**	.855**		
DS C - Org Filt mgl-1+1		.693**	.713**		.692**					.808**	.885**		
US Cadmium - Cd ugl-1										.766**			
DS Cadmium - Cd ugl-1													
DS Cadmium - Cd ugl-1+1													
US Chromium -Cr ugl-1										.717**			
DS Chromium -Cr ugl-1													
DS Chromium -Cr ugl-1+1													
US COD as O2 mgl-1	0.723	.715**	.689**	0.691	.692**								
DS COD as O2 mgl-1													
DS COD as O2 mgl-1+1													
US Copper - Cu ugl-1										.724**			
DS Copper - Cu ugl-1													
DS Copper - Cu ugl-1+1													
US Lead - as Pb ugl-1			.687**										.675**
DS Lead - as Pb ugl-1													
DS Lead - as Pb ugl-1+1													
US N Oxidised mgl-1	-0.842			-0.858	.873**	.793**	.736**	.701**					.873**
DS N Oxidised mgl-1	-0.96			-0.99	1.000**	.978**	.952**	.921**			.789**		.911**
DS N Oxidised mgl-1+1	-0.863	-0.902	-0.949	-0.916	.940**	.962**	.973**	.989**			.802**		.877**
US pH (pH units)									.762**			-0.703	
DS pH (ph units)				-0.672									
DS pH (ph units) +1													
US Sld Sus@105C mgl-1	0.869	.884**	.881**	0.874	.893**	.880**	.880**	.851**					-0.887
DS Sld Sus@105C mgl-1	0.714	.693**	0.682	0.739	.714**	.754**	.741**	.705**					
DS Sld Sus@105C mgl-1+1													
US Zinc - as Zn ugl-1										0.842			
DS Zinc - as Zn ugl-1													
DS Zinc - as Zn ugl-1+1													
Rainfall													
Rainfall -1	0.79	.803**	.791**	0.689	.740**	.711**	.722**	.738**			.675**		
Rainfall -2	0.691	.747**	.758**	0.772	.762**	.813**	.804**	.806**			.797**		.805**
Flow US	1	.949**	.916**	0.942	.935**	.924**	.914**	.909**	.425**	.570**	.777**	.573**	.864**
flowus+.25	0.949	1.000**	.951**	0.936	.924**	.914**	.908**	.905**	.440**	.572**	.789**	.573**	-0.885
flowUS+.5	0.916	.951**	1.000**	0.923	.914**	.907**	.905**	.902**	.424**	.559**	.797**	.568**	-0.92
level US		.949**	.916**	0.942	.935**	.924**	.914**	.909**	.425**	.570**	.777**	.573**	.864**
levelUS +.25	0.949		.951**	0.936	.924**	.914**	.908**	.905**	.440**	.572**	.789**	.573**	-0.885
levelUS+.5	0.916	.951**		0.923	.914**	.907**	.905**	.902**	.424**	.559**	.797**	.568**	.920**
level DS	0.942	.936**	.923**		.988**	.963**	.934**	.903**		.612**	.793**	.573**	.891**
levelDS-.25	0.935	.924**	.914**	0.988		.988**	.963**	.933**		.618**	.813**	.573**	.874**
levelDS-.5	0.924	.914**	.907**	0.963	.988**		.988**	.962**		.614**	.827**	.571**	.860**
levelDS-.75	0.914	.908**	.905**	0.934	.963**	.988**		.987**	.355**	.601**	.833**	.573**	.840**
levelDS-1.0	0.909	.905**	.902**	0.903	.933**	.962**	.987**		.389**	.591**	.833**	.573**	.823**
US cont Temp degC	0.425	.440**	.424**				.355**	.389**				.573**	
US cont SpCond mScm-1	-0.57	.572**	.559**	-0.612	.618**	.614**	.601**	.591**			.826**		0.616
US cont DO %sat	0.777	.789**	.797**	0.793	.813**	.827**	.833**	.833**		.826**			-0.814
US cont Ammonia mgl-1	0.573	.573**	.568**	0.573	.573**	.571**	.573**	.573**	.573**				-0.516
US cont pH (pH Units)	-0.864	.885**	.920**	-0.891	.874**	.860**	.840**	.823**		.616**	.814**	.516**	

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.13 November storm event 2003 significant rank correlations (Spearman's test) (p>0.05)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Nov storm significant 1	US BOD	DS BOD	DS BOD+1	DS C-org F	DS C org F+1	US Cd	DS Cd	DS Cd+1	US Cr	DS Cr	DS Cr+1	US COD	DS COD	DS COD+1	US Cu	DS Cu	DS Cu+1	US Pb	DS Pb	DS Pb+1	US TON
2	US BOD ATU mgl-1									.591*						.611*						
3	DS BOD ATU mgl-1									.555*						.597*			.548*			
4	DS BOD ATU mgl-1+1																					
5	US C - Org Filt mgl-1																					
6	DS C - Org Filt mgl-1									.634*						.653*						
7	DS C - Org Filt mgl-1+1						.575*															
8	US Cadmium - Cd ugl-1					0.575					.581*						.581*					
9	DS Cadmium - Cd ugl-1															.582*			.582*			
10	DS Cadmium - Cd ugl-1+1																					
11	US Chromium -Cr ugl-1	.591*	.555*		.634*									.535*					.586*	.563*		
12	DS Chromium -Cr ugl-1						.581*												.543*			
13	DS Chromium -Cr ugl-1+1													.578*								
14	US COD as O2 mgl-1																					.626*
15	DS COD as O2 mgl-1									.535*		.578*				.617*						
16	DS COD as O2 mgl-1+1																					
17	US Copper - Cu ugl-1	.611*	.597*		.653*									.617*						.601*		
18	DS Copper - Cu ugl-1						.581*															
19	DS Copper - Cu ugl-1+1																					
20	US Lead - as Pb ugl-1		.548*					.582*		.586*	.543*											
21	DS Lead - as Pb ugl-1									.563*						.601*						
22	DS Lead - as Pb ugl-1+1																					
23	US N Oxidised mgl-1												.626*									
24	DS N Oxidised mgl-1	.553*	.567*		.613*									.554*					.660*	.556*		
25	DS N Oxidised mgl-1+1		.564*										.599*	.591*					.586*	.560*		
26	US pH (pH units)		.643*				.549*	.629*						.641*			.640*			.610*		.640*
27	DS pH (ph units)									.561*									.542*			
28	DS pH (ph units) +1		.675*								.560*				.627*		.674*		.608*			
29	US Sld Sus@105C mgl-1		.648*					.629*						.624*						.576*		
30	DS Sld Sus@105C mgl-1																		.631*			
31	DS Sld Sus@105C mgl-1+1													.561*								
32	US Zinc - as Zn ugl-1					.626*														.552*		
33	DS Zinc - as Zn ugl-1						.581*												.550*			
34	DS Zinc - as Zn ugl-1+1																					
35	Rainfall																					
36	Rainfall -1				.683*	.629*							.618*						.574*			.591*
37	Rainfall -2				.584*	.635*																.628*
38	Flow US	.553*	.576*		.596*	.648*								.576*					.572*	.569*		
39	flowus+.25				.614*														.639*			
40	flowUS+.5				.590*																	
41	level US	.553*	.576*		.596*	.648*								.576*					.572*	.569*		
42	levelUS +.25				.614*														.639*			
43	levelUS+.5				.590*																	
44	level DS	.569*	.599*		.581*	.674*								.593*					.628*	.612*		
45	levelDS-.25	.553*	.567*		.613*									.554*					.660*	.556*		
46	levelDS-.5	.542*	.611*		.591	.670*		.555*					.657*	.607*					.603*	.604*		
47	levelDS-.75		.594*		.574*	.659*		.548*					.640*	.603*					.640*	.565*		
48	levelDS-1.0		.550*		.560*	.676*							.609*	.568*					.603*			
49	US cont Temp degC									.603*						.627*						
50	US cont SpCond mScm-1																					
51	US cont DO %sat																					.635*
52	US cont Ammonia mgl-1	.609*	.559*	.628*			.559*	.560*	.629*	.608*	.608*	.627*	.608*	.608*	.628*	.608*	.608*	.627*	.608*	.608*	.627*	.608*
53	US cont pH (pH Units)				.583*	.683*							.623*									
54																						

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation

Table 7.13 November storm event 2003 significant rank correlations (Spearman's test) (p>0.05)

	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	Nov storm significant2	DS TON	DS TON +1	US pH	DS pH	DS pH +1	US SS	DS SS	DS SS+1	US Zn	DS Zn	DS Zn +1	Rainfall	Rainfall -1	Rainfall -2	Flow US	flowus+.25	flowUS+.5
2	US BOD ATU mgl-1	.553*														.553*	.553*	.569*
3	DS BOD ATU mgl-1	.567*	.564*	.643*	.796*	.675*	.648*									.576*	.576*	.599*
4	DS BOD ATU mgl-1+1																	
5	US C - Org Filt mgl-1																	
6	DS C - Org Filt mgl-1	.613*												.638*	.584*	.596*	.614*	.590*
7	DS C - Org Filt mgl-1+1									.626*				.629*	.635*	.648*		
8	US Cadmium - Cd ugl-1			.549*							.581*							
9	DS Cadmium - Cd ugl-1			.629*			.629*											
10	DS Cadmium - Cd ugl-1+1																	
11	US Chromium -Cr ugl-1				.561*													
12	DS Chromium -Cr ugl-1					.560*												
13	DS Chromium -Cr ugl-1+1																	
14	US COD as O2 mgl-1		.599*											.618*				
15	DS COD as O2 mgl-1	.554*	.591*	.641*			.624*		.561*							0.578		
16	DS COD as O2 mgl-1+1					.627*												
17	US Copper - Cu ugl-1																	
18	DS Copper - Cu ugl-1			.640*		.674*												
19	DS Copper - Cu ugl-1+1																	
20	US Lead - as Pb ugl-1	.660*	.586*		.542*	.608*		.631*						.574*		.572*	0.639	
21	DS Lead - as Pb ugl-1	.556*	.560*	.610*			.576*			.552*						.569*		
22	DS Lead - as Pb ugl-1+1																	
23	US N Oxidised mgl-1			.640*										.591*	.628*			
24	DS N Oxidised mgl-1			.549*	.653*								.547*					
25	DS N Oxidised mgl-1+1					.563*			.643*									
26	US pH (pH units)	.549*			.637*		.641*	.640*		.582*						.543*	.559*	.580*
27	DS pH (ph units)	.653*		.637*			.632*									.636*		
28	DS pH (ph units) +1		.563*				.573*		.656*		.644*				.586*			
29	US Sld Sus@105C mgl-1			.641*	.632*	.573*												
30	DS Sld Sus@105C mgl-1			.640*										.545*	.564*			
31	DS Sld Sus@105C mgl-1+1		.643*															
32	US Zinc - as Zn ugl-1			.582*														
33	DS Zinc - as Zn ugl-1																	
34	DS Zinc - as Zn ugl-1+1																	
35	Rainfall	.547*														.570*		
36	Rainfall -1							.545*										
37	Rainfall -2					.586*		.564*										
38	Flow US			.543*	.636*								.570*					
39	flowus+.25			-0.559														
40	flowUS+.5			-0.58														
41	level US			.543*	.636*								.570*					
42	levelUS +.25			-0.559														
43	levelUS+.5																	
44	level DS			.549*									.547*					
45	levelDS-.25			.549*	.653*								.547*					
46	levelDS-.5				.631*				.610*				.584*					
47	levelDS-.75				.563*	.593*			.681*				.563*					
48	levelDS-1.0					.593*			.676*				.599*					
49	US cont Temp degC		.582*															
50	US cont SpCond mSim-1														.628*			
51	US cont DO %sat						0.634			-0.538								
52	US cont Ammonia mgl-1	.608*	.627*		-0.545	-0.656	0.608	0.608	0.627	0.608	.608*	.627*						
53	US cont pH (pH Units)			0.629	0.561			-0.561						.630*				
54																		

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.13 November storm event 2003 significant rank correlations (Spearman's test) (p>0.05)

	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC
1	Nov storm significant3	level US	levelUS +.25	levelUS+.5	level DS	levelDS-.25	levelDS-.5	levelDS-.75	levelDS-1.0	US cont Temp	US cont SC	US cont DO	US cont NH3	US cont pH	
2	US BOD ATU mgl-1					.553*	.542*						.609*		
3	DS BOD ATU mgl-1					.567*	.611*	.594*	.550*				.559*		
4	DS BOD ATU mgl-1+1												.628*		
5	US C - Org Filt mgl-1														
6	DS C - Org Filt mgl-1	.596*	.614*	.590*	.581*	.613*	.591*	.574*	.560					.583*	
7	DS C - Org Filt mgl-1+1	.648*			.674*		.670*	.659*	.676*					0.683	
8	US Cadmium - Cd ugl-1												.559*		
9	DS Cadmium - Cd ugl-1						.555*	.548*					.560*		
10	DS Cadmium - Cd ugl-1+1												.629*		
11	US Chromium -Cr ugl-1									.603*			.608*		
12	DS Chromium -Cr ugl-1												.608*		
13	DS Chromium -Cr ugl-1+1												.627*		
14	US COD as O2 mgl-1						.657*	.640*	.609*				.608*	.623*	
15	DS COD as O2 mgl-1	0.578			0.593	.554*	.607*	.603*	.568*				.608*		
16	DS COD as O2 mgl-1+1												.628*		
17	US Copper - Cu ugl-1									.627*			.608*		
18	DS Copper - Cu ugl-1												.608*		
19	DS Copper - Cu ugl-1+1												.627*		
20	US Lead - as Pb ugl-1	.572*	0.639		.628*	.660*	.603*	.640*	.603*				.608*		
21	DS Lead - as Pb ugl-1	.569*			.612*	.556*	.604*	.565*					.608*		
22	DS Lead - as Pb ugl-1+1												.627*		
23	US N Oxidised mgl-1											.635*	.608*		
24	DS N Oxidised mgl-1									.582*			.608*		
25	DS N Oxidised mgl-1+1												.627*		
26	US pH (pH units)	.543*	.559*	.580*	.549*	.549*								.629*	
27	DS pH (ph units)	.636*				.653*	.631*	.563*					.545*	.561*	
28	DS pH (ph units) +1							.593*	.593*				.656*		
29	US Sld Sus@105C mgl-1											.634*	.608*		
30	DS Sld Sus@105C mgl-1												.608*	.561*	
31	DS Sld Sus@105C mgl-1+1						.610*	.681*	.676*				.627*		
32	US Zinc - as Zn ugl-1											.538*	.608*		
33	DS Zinc - as Zn ugl-1												.608*		
34	DS Zinc - as Zn ugl-1+1												.627*		
35	Rainfall	.570*			.547*	.547*	.584*	.563*	.599*						
36	Rainfall -1													.630*	
37	Rainfall -2										.628*				
38	Flow US														
39	flowus+.25														
40	flowUS+.5														
41	level US														
42	levelUS +.25														
43	levelUS+.5														
44	level DS									.306*					
45	levelDS-.25									.305*					
46	levelDS-.5									.322*					
47	levelDS-.75														
48	levelDS-1.0														
49	US cont Temp degC				0.306	.305*	.322*				.292*			.316*	
50	US cont SpCond mScm-1									.292*					
51	US cont DO %sat														
52	US cont Ammonia mgl-1														
53	US cont pH (pH Units)									.316*					
54															

Key to Tables 7.9, 7.10 and 7.11:
US =upstream
DS = downstream
Numbers in red = negative correlation
Yellow shaded box = 1.0 correlation

Table 7.14 Summary of Spearman's rank correlations against river level during November storm event.

Key: ↑ increase ↓ decrease (highly significant) ◙ no correlation ↑↓ significant results – no data

→ US results	rainfall	level	BOD	C-org filter	COD	Cu	Pb	Zn	pH	SS	flow	Temp.	SC	DO % satn	NH_4^+N	Cont. pH	TON
Rain -1hr	◙	↑	◙	◙	◙	◙	◙	◙	◙	↑	↑	◙	◙	↑	◙	◙	◙
Rain -2hr	◙	↑	◙	↓	↑	◙	↑	◙	◙	↑	↑	◙	◙	↑	◙	↓	◙
level	↑	-	↑	◙	↑	◙	↑	◙	↓	↑	↑	↑	↓	↑	↑	↓	↓
→ DS results	rainfall	level	BOD	C-org filter	COD	Cu	Pb	Zn	pH	SS	flow	Temp.	SC	DO % satn	NH_4^+N	Cont. pH	TON
Rain -1hr	◙	↑	↑	↓	◙	◙	◙	◙	◙	↑	-	-	-	-	-	-	↓
Rain -2hr	◙	↑	↑	↓	◙	◙	◙	◙	◙	↑	-	-	-	-	-	-	↓
level	↑	-	↑	↓	↑	◙	↑	◙	↓	↑	-	-	-	-	-	-	↓
General trend	↑	↑	↑	↓	↑	◙	↑	◙	↓	↑	↑	◙	↓	↑	↑	↓	↓

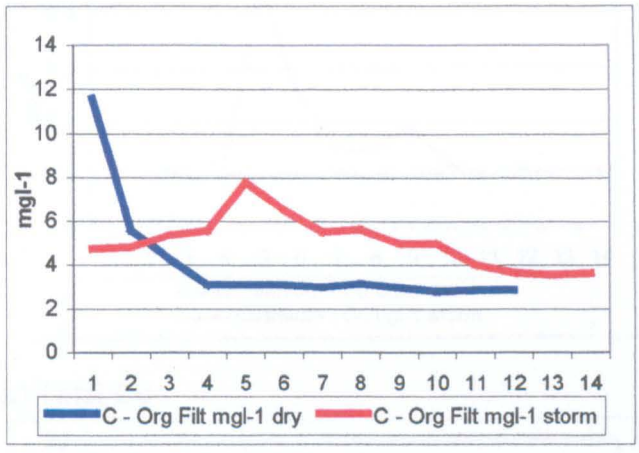
Key to table: US upstream (Meadow St.) DS downstream (Humber Avenue)
Rain figures shown as – 1 hour and –2 hour to allow for 1 hour and 2 hour infiltration

The results for the storm event in November 2003 showed that upstream and downstream of the city centre, the SS, BOD, COD and ammonium increased with an increase in river level, as shown in table 4.17, but there was no significant correlation, using Spearman's rank correlation analysis, between river level and the heavy metals identified, other than Pb. The heavy metals all show a peak concentration during the initial rainfall period before river levels rose significantly, which may be associated with a first flush effect relating to streets dusts being deposited in the watercourse (Figure 2.2, *from* Charlesworth and Lees, 1999), or sediment-related heavy metals being flushed through drainage systems and the culverted watercourses, (Deletic, 1998), particularly

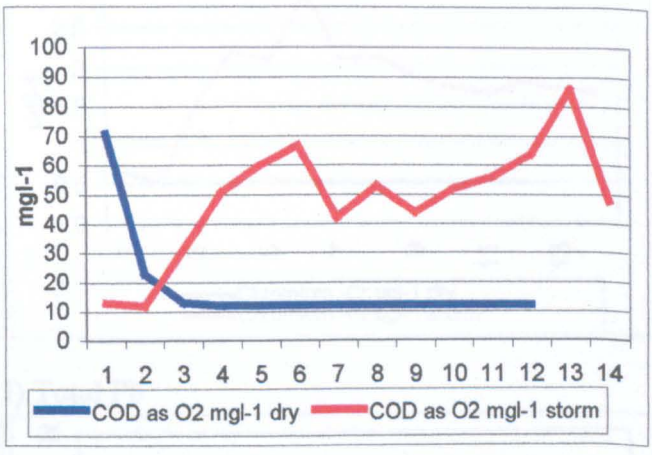
as levels are greater for Zn, Cu, Pb and Cr at Humber Avenue downstream of the city. Lead is particle-associated (Lundberg *et al.*, 1999), and mostly found in sediment deposits (Charlesworth and Lees, 1999). The increase in concentration identified with an increase in river level and SS later in the event, could be due to sediment disturbance as a result of turbulent flows in the culverted river channel (Borchardt and Sperling, 1997). Secondary peaks for heavy metals were lower for the following continuous rainfall and peak rainfall periods, as shown in Figures 7.33 to 7.37. The heavy metals generally showed a highly significant correlation ($p>0.01$) with each other, (Table 7.11), and BOD, and highly significant negative correlations with pH. Only Cd showed a highly significant correlation (when using Spearman's rank correlation analysis), with filtered Organic C, indicating that the metal was probably present in soluble form. This compares with the findings of Hares and Ward (1999) and Lundberg *et al.*, (1999). Only Pb had a highly significant correlation with SS (correlation coefficient, 0.77 at Meadow Street and 0.912 at Humber Avenue) indicating that it was probably associated with particulate matter, as discussed above. The pH value and SC concentration dropped at both sites with increased flow, and DO saturation at Meadow Street increased, as in the March 2001 event. The relative reduction in heavy metals generated during the storm events following remediation indicates that the trade effluent content component has possibly decreased as a result of the removal of the combined sewer overflows, the reduction in manufacturing industry in the city and improvements in environmental management at industrial and commercial sites. Possible sources for the pollutants remaining (objective 5), will be discussed in consideration of a water quality model for the catchment during storm events, in Chapter 8. A comparison between the September dryweather investigation and November storm event is given in Appendix 10, and in Figures 7.42 (a-p) for Meadow Street, and Figures 7.43 (a-j), for Humber Avenue.

Figures 7.42 (a-p) Meadow Street September dry weather against November storm comparison 2003

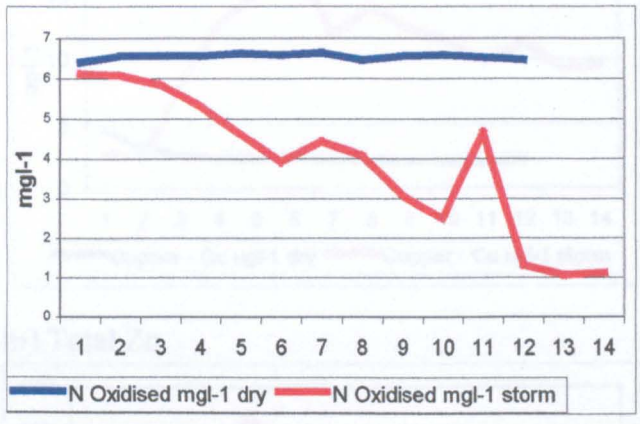
a) Filtered organic C



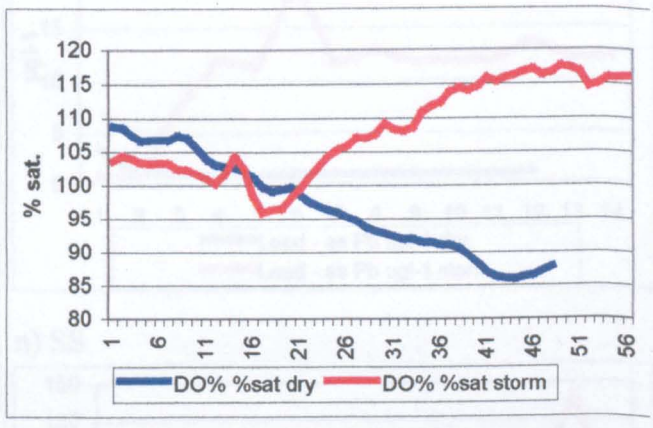
b) COD



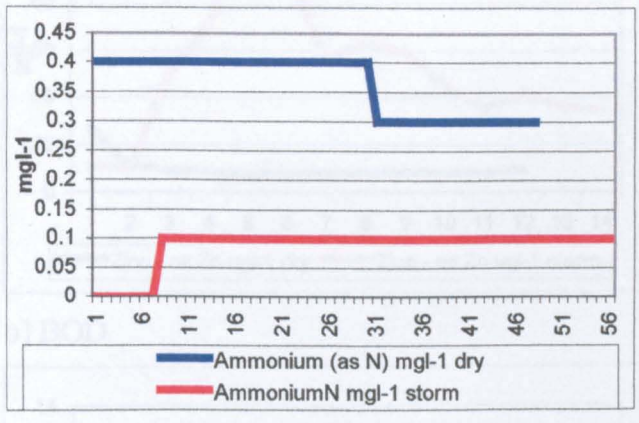
c) TON



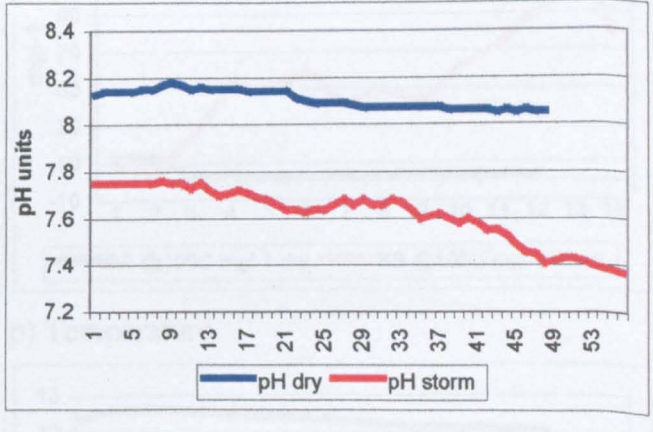
d) DO % saturation



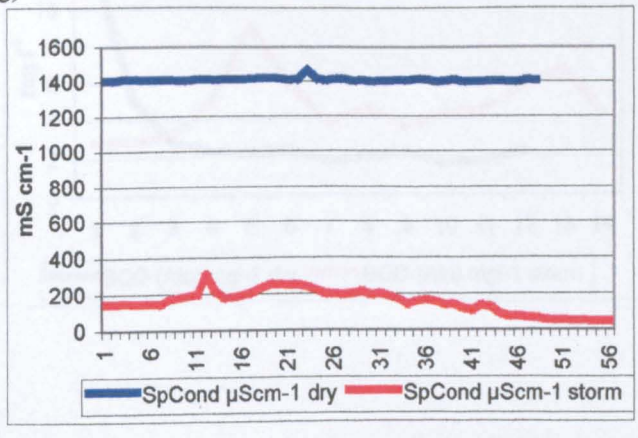
e) NH_4^+ N



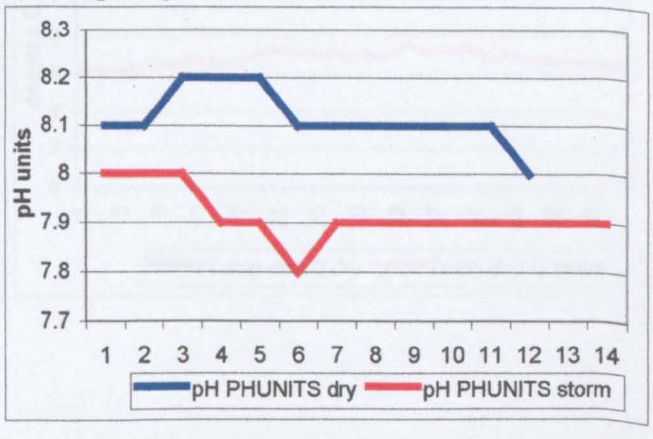
f) Continuous pH



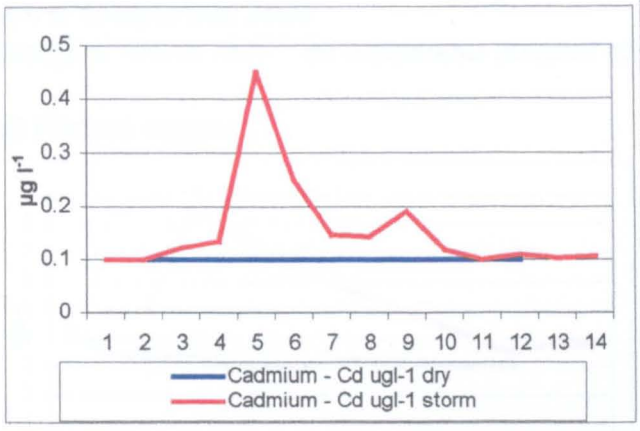
g) SC



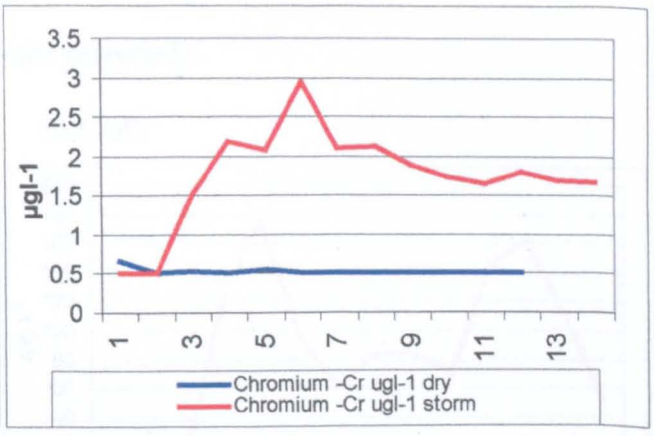
h) Sampled pH



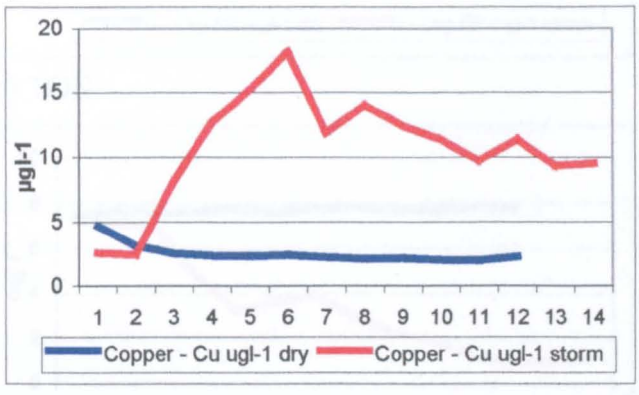
i) Total Cd



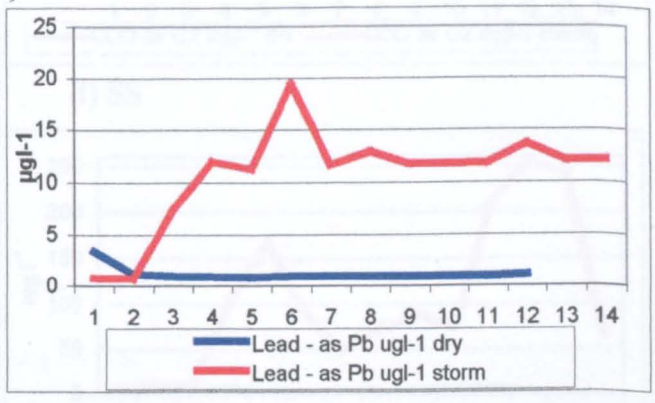
j) Total Cr



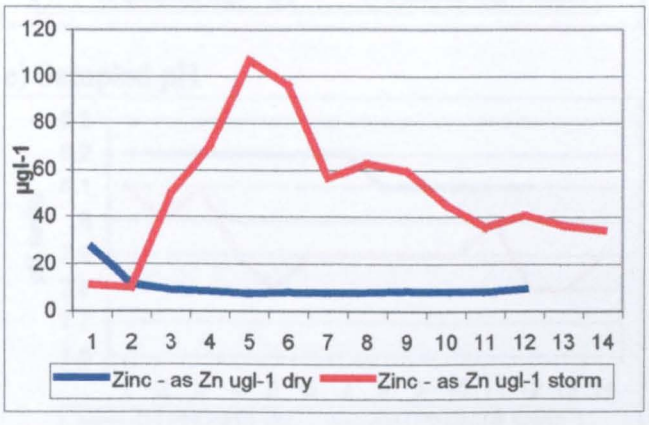
k) Total Cu



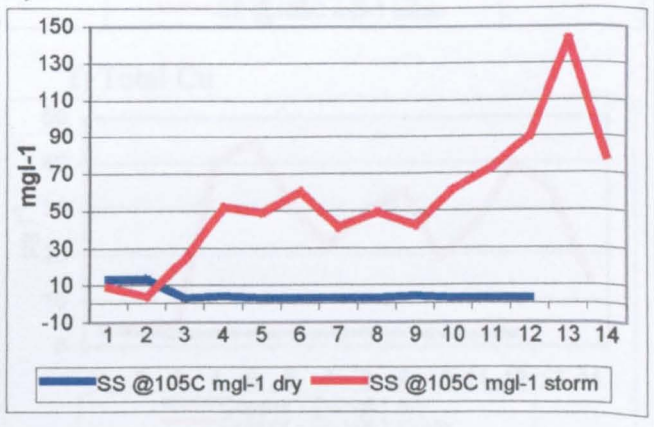
l) Total Pb



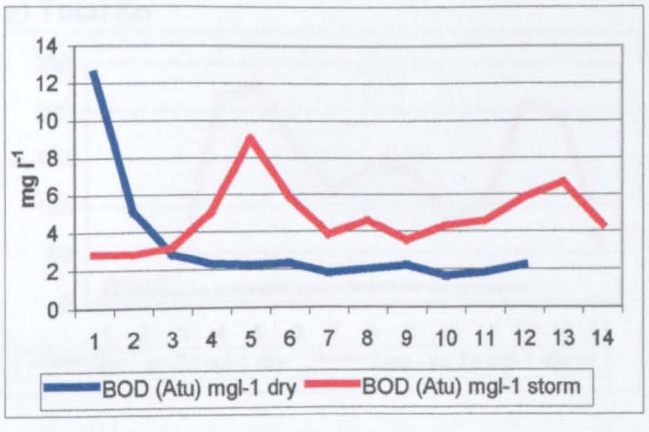
m) Total Zn



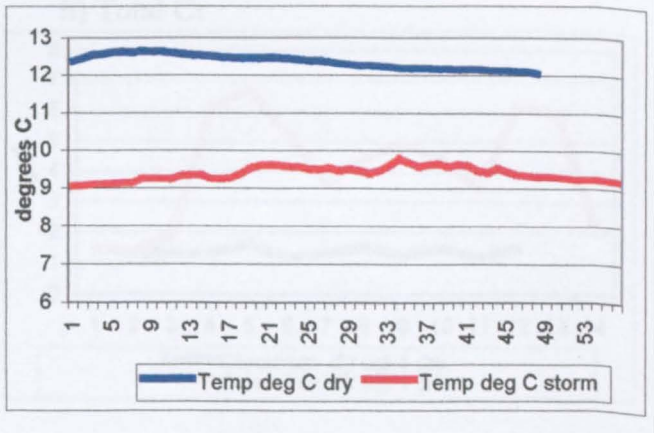
n) SS



o) BOD

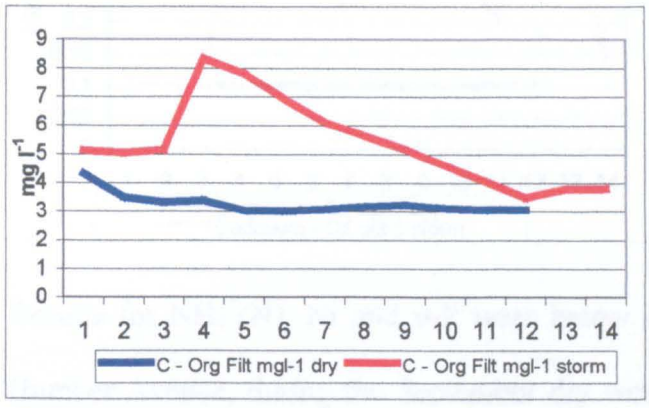


p) Temperature

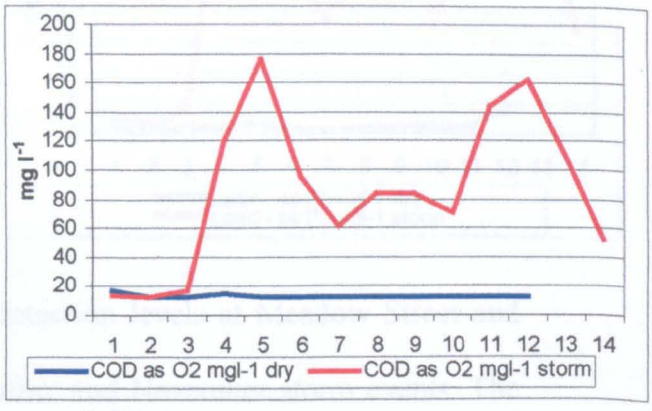


Figures 7.43 (a-j) Humber Avenue September dry weather against November storm comparison 2003
(sampled results only – no continuous monitor results recorded)

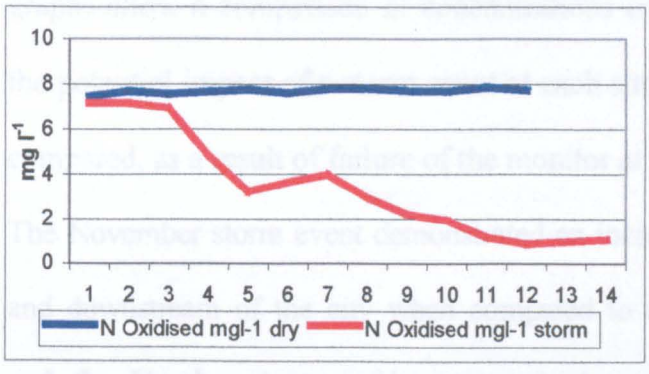
a) Filtered organic C



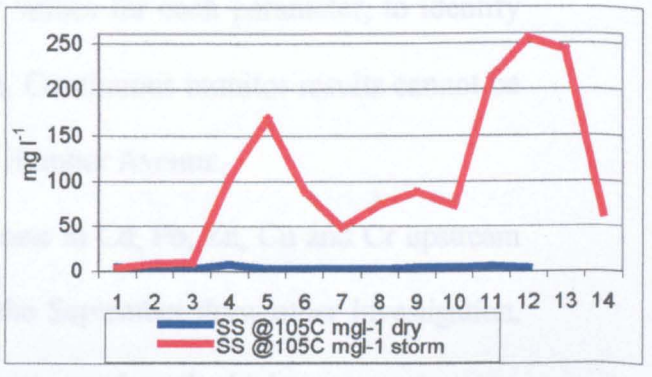
b) COD



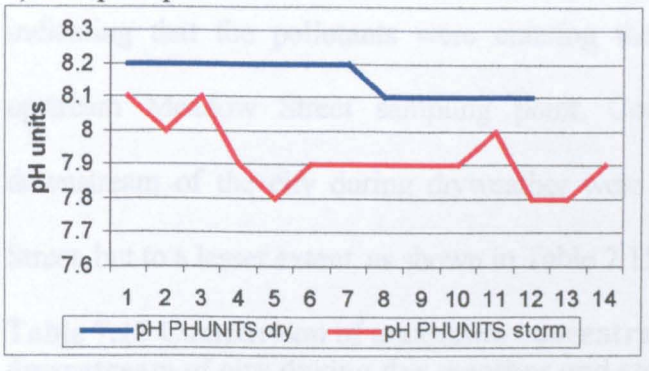
c) TON



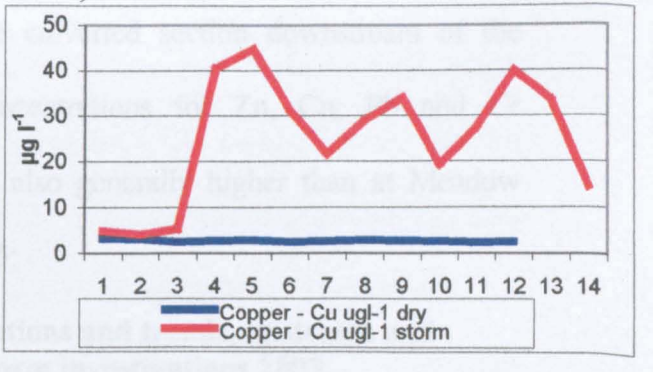
d) SS



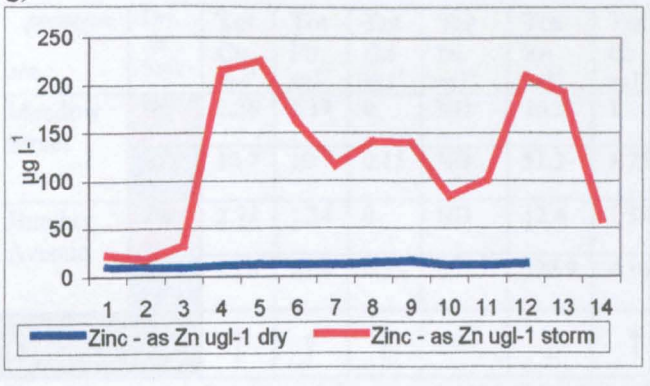
e) Sampled pH



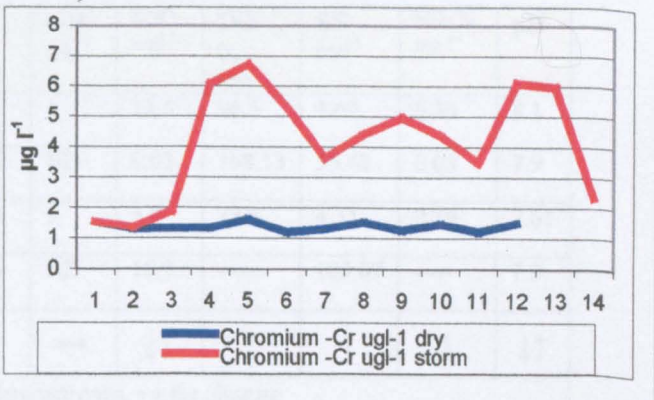
f) Total Cu



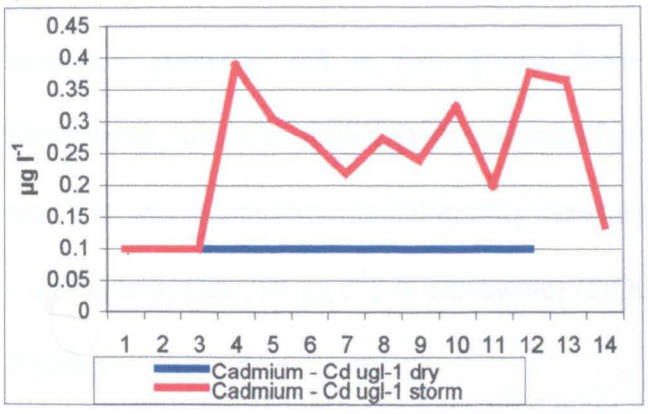
g) Total Zn



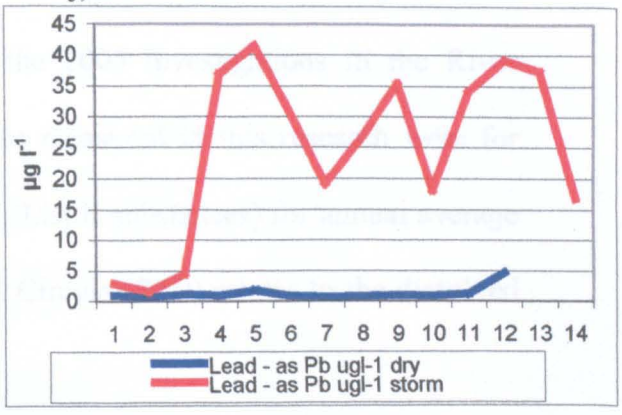
h) Total Cr



i) Total Cd



j) Total Pb



Results for NH_4^+(N), Ni and σ-P were below detection levels at Meadow Street and Humber Avenue, during the September dry weather and November storm events. The graphs allow a comparison of concentrations or values for each parameter, to identify the potential impact of a storm event at each site. Continuous monitor results cannot be compared, as a result of failure of the monitor at Humber Avenue.

The November storm event demonstrated an increase in Cd, Pb, Zn, Cu and Cr upstream and downstream of the city when compared to the September dryweather investigation, and the Humber Avenue (downstream) site gave consistently higher concentrations, indicating that the pollutants were entering the culverted section downstream of the upstream Meadow Street sampling point. Concentrations for Zn, Cu, Pb and Cr downstream of the city during dryweather were also generally higher than at Meadow Street, but to a lesser extent, as shown in Table 7.15:

Table 7.15 Comparison of maximum concentrations and trends, upstream and downstream of city during dry weather and storm investigations 2003.

parameter / Site	Dry or Rain	Tot Cu µg l-1	Tot Pb µg l-1	Tot Cd µg l-1	Tot Ni µg l-1	Tot Zn µg l-1	Tot Cr µg l-1	σ-P mgl-1	BOD mgl-1	DO % satn	SS mgl-1	NH_4^+N mg l-1	pH
Meadow Street	Dry	2.56	1.19	0	ND	10.3	1	1	12.5	96.5	4.69	0.36	8.1
	Rain	10.7	10.7	0.15	ND	51.2	1.75	ND	9.03	108.13	55.43	0.08	7.9
Humber Avenue	Dry	2.73	1.34	0	ND	12.4	1.38	1	3.7	77.3	4.31	0.36	7.61
	Rain	25.0	24.6	0.25	ND	122.9	4.16	ND	16.9	-----	103.07	-----	7.9
Trend during rainfall		↑	↑	↑	↔	↑	↑	↔	↓↑	↑	↑	↓	↓↑

Key: ↑ increase ↓ decrease ↓↑ decrease upstream, increase downstream, ↔ no change
ND non-detected, Tot Total

As discussed in Section 7.4 the only heavy metal reported in sufficient quantity to present a potential risk to fish species from the 2003 investigations in the River Sherbourne, was Cu, although the concentrations measured in this research were for total Cu, and the environmental quality standard (List II substances) for annual average Cu concentration (10 $\mu g\ l^{-1}$) in freshwater (DOE Circular 7/89) relates to the dissolved fraction.

7.3.3 Current Pollution levels in the River Sherbourne– Comparisons with previous data and published literature

Pollution in the form of sanitary determinands (BOD, NH_4^+N and ortho-P) showed decreased levels during the 2003 storm event (Section7.2.3), and the DO saturation levels increased when compared to previous data. This is a marked improvement in comparison to the measurements recorded during Phase 2 and the early post-remediation phase (Phase 3), as shown in Tables 7.6 and 7.16. This may mean that occasional storm discharges, as a result of the single remaining high-level storm-relief outfall on the Albany Road drainage system, or intermittent domestic or industrial discharge, have less impact on the watercourse, with only short-term implications for ecological status. However, as Fundamental Intermittent Standards (Section 7.3.1) are still breached in the culverted watercourse for dissolved oxygen (table 2.12), any resident cyprinid fish would still be at risk of mortality, or suffer a reduction in the ability to maintain viable fish populations (Klein, 1972). Fundamental Intermittent Standards for ammonium (table 2.13) were met, with total ammonium levels below the guidelines for non-ionised ammonia. A comparison of water quality results for each Phase is made in Chapter 8, in consideration of objectives 3 and 5.

Table 7.16 Comparison of mean values for some sanitary determinands (Phases 2 and 3), and heavy metals for Phase 3 featured events in 2001 and 2003.

Featured event		Early data			March 2001 storm event			September 2003 dryweather event			November 2003 storm event		
		min	max	mean	min	max	mean	min	max	mean	min	max	mean
BOD mg l^{-1}	US	----	----	----	----	----	----	1.7	12.5	3.25	2.85	9.03	4.76
	DS	----	----	----	2.4	11.5	5.04	1.5	3.7	1.88	2.85	16.9	8.03
Suspended Solids mg l^{-1}	US	----	----	----	----	----	----	3	13	4.69	4	143	55.43
	DS	----	----	----	10	365	70.21	3	8	4.31	4	255	103.07
DO % satn	US	39.1	110.2	83.6	76.0	86.7	81.77	86.0	108.8	96.54	96.0	117.6	108.14
	DS	9.8	182.5	48.63	78.7	93.8	86.79	69.4	93.9	77.3	----	----	----
$NH_4^+(N)$ continuous	US	0	2.0	1.0	0.5	1.9	0.89	0.3	0.4	0.36	0	0.1	0.08
	DS	0	14.7	1.82	0.1	0.5	0.247	0.3	0.4	0.36	----	----	----
$NH_4^+(N)$ sampled	US	----	----	----	----	----	----	1	1	0.5	0.5	0.5	0.5
	DS	----	----	----	0.54	5.53	1.65	1	1	0.5	0.5	0.5	0.5
PH pH units	US	6.07	8.5	7.95	7.72	8.04	7.87	8.1	8.2	8.1	7.8	8.0	7.9
	DS	3.85	9.1	8.05	7.65	7.97	7.75	7.5	7.8	7.61	7.8	8.1	7.9
Total Cu µg l^{-1}	US	----	----	----	----	----	----	2	5	2.56	2.5	18.2	10.65
	DS	----	----	----	6.5	46.4	15.81	2	3	2.73	4.19	44.6	24.97
Total Pb µg l^{-1}	US	----	----	----	----	----	----	1	3	1.19	0.77	19.5	10.71
	DS	----	----	----	2.03	61.1	15.38	1	5	1.34	1.67	41.5	24.64
Total Cd µg l^{-1}	US	----	----	----	----	----	----	0	0	0	0.1	0.5	0.15
	DS	----	----	----	0.102	0.546	0.256	0	0	0	0.1	0.4	0.25
Total Ni µg l^{-1}	US	----	----	----	----	----	----	<5	<5	5	<5	<5	5
	DS	----	----	----	5.54	8.63	6.62	<5	<5	5	<5	<5	5
Total Zn µg l^{-1}	US	----	----	----	----	----	----	8	27	10.32	10.2	107.0	51.24
	DS	----	----	----	15.2	147.0	50.60	10	16	12.42	19.1	226.0	122.93
Total Cr µg l^{-1}	US	----	----	----	----	----	----	1	1	1	0.5	2.94	1.75
	DS	----	----	----	0.598	5.47	2.062	1	2	1.38	1.36	6.71	4.16
Ortho-P Mg l^{-1}	US	----	----	----	----	----	----	1	1	1	0.5	0.5	0.5
	DS	----	----	----	0.6	0.6	0.60	1	1	1	0.5	0.5	0.5

Key to table: ---- No data Mean

The pollutant concentrations recorded in this research are comparable to urban runoff values measured by Laws (1993), as discussed in Section 2.2.1, and are considerably lower than mean concentrations identified for residential and commercial source areas by Bannerman *et al.* (1993) as given in Table 2.2, and discussed in Chapter 2. Laws (1993) identified reasonable values (table 2.1) for BOD, SS and total P values that can be compared against the values recorded for post remedial featured storms, as given in table 7.16. The Coventry data exceeded the 227 mg l^{-1} value suggested for SS, with maximum concentrations of 365 mg l^{-1} and 255 mg l^{-1} respectively, for the Humber Road site during the storms in March 2001 and November 2003. The values for Meadow Street were all below the suggested values. Ortho-phosphate concentrations were also higher than Laws' suggested values (Laws, 1993) for total P, though it should be noted that the higher levels (1 mg l^{-1}) were maintained through dry weather in the September 2003 investigation, and were still considerably lower than the value suggested for raw sewage (10 mg l^{-1}). It is likely therefore, since levels for σ-P are identical upstream and downstream of the city, that nutrient sources including P, are predominantly entering the River Sherbourne system above the city; arising from non-point (Section 2.11) agricultural sources, or by discharge from private sewage treatment plants to the Pickford Brook, as discussed in Section 3.3. The downstream maximum values for BOD in the River Sherbourne were lower (at 11.5 mg l^{-1} and 16.9 mg l^{-1}) for the 2001 and 2003 storm events, than the 'reasonable' values suggested by Laws (1993) at 17 mg l^{-1}. Mean values for Humber Avenue reached 5.04 and 8.03 respectively.

All results for the River Sherbourne were in the same order of the EMC calculations of Lee and Bang (2000) as identified in table 2.3. The event mean concentrations calculated for the River Sherbourne catchment during the November storm event are given in Section 7.4a. The downstream level monitor at Whitley is a level only monitor

and no flow gauging has been carried out to date at this site (2006). The runoff could not therefore be calculated as a difference between the upstream and downstream flow monitoring points. All calculations therefore take the total river flow entering the culvert as pollutant volume.

a) Event Mean Concentrations (EMC) November 2003 storm event

Event Mean Concentrations for the November 2003 sanitary determinands can be calculated according to the method used by Lee and Bang, (2000) and Brezonik and Stadelmann (2002), as discussed in Section 2.1:

EMC is defined as the pollutant load divided by the total runoff volume and is represented as:

$$EMC\ (mg\ l^{-1}) = \frac{\Sigma Qi\ Ci}{\Sigma Qi}$$

(total load) / (total runoff volume)

(Where Qi = water volume (l) and Ci = concentration of pollutant mg l^{-1}.)

The results are given in Table 7.17:

Table 7.17 Event Mean Concentrations for November 2003 storm event

Parameter (mg l^{-1})	Meadow Street	Humber Avenue	Parameter (µg l^{-1}) (except pH)	Meadow Street	Humber Avenue
BOD	5.16	7.41	Cd	0.12	0.23
COD	60.21	89.28	Zn	42.49	94.03
NH_4^+N	0	0	Cr	1.76	3.73
C-Org.Filt.	4.2	4.56	Cu	10.65	22.54
TON	2.33	1.82	Pb	12.33	24.54
σ-P	0	0	Ni	0	0
SS	84.49	110.0	pH	7.9	7.93

The BOD result for the R.Sherbourne was lower than EMC values for BOD found at nine sites by Lee *et al.*, (2000) in residential or industrial areas during 34 storm events in Korea (Section 2.2.1), but concentrations for COD, TON and Pb were all greater than the Korean findings (Table 2.3). This possibly reflects the position that, with the removal of significant sewage contamination on the River Sherbourne, other pollutant

sources, such as urban runoff, agricultural land drainage and vehicle emissions contribute a major component of the current polluting load. Each site monitored for urban runoff is site specific (EPA, 1983), and the type of urban land-use plays an important role in determining environmental impact (Mulcahy, 1990). The River Sherbourne has a complex mixture of agricultural, residential, highway and industrial areas draining to it, as discussed in Section 3.2, and shows a different pollutant profile to the specific residential and industrial areas studied in Korea by Lee *et al.*, (2000), with all parameters giving significantly lower results than mean values identified for residential and commercial areas, by Bannerman *et al.* (1993).

The results for Humber Avenue show that the culverted watercourses draining to the River Sherbourne are still having an impact on the level of pollutants downstream, but the levels are well within guideline or mandatory values for the EC Freshwater Fish Directive (78/659/EEC), as given in table 2.10. The relatively high mean BOD concentrations, particularly at Humber Avenue during the storm event, are a matter of concern, as they are only just within UK derogated values, but would fall outside guideline values for cyprinid fisheries under the Directive.

b) Cumulative curves and first flush phenomena

The Event Mean Concentration gives an indication of the average concentration for each parameter, taking into account river flows during the storm event. Where flows are available, a graph of cumulative pollutant mass against cumulative volume can be made, as shown in Figure 7.44:

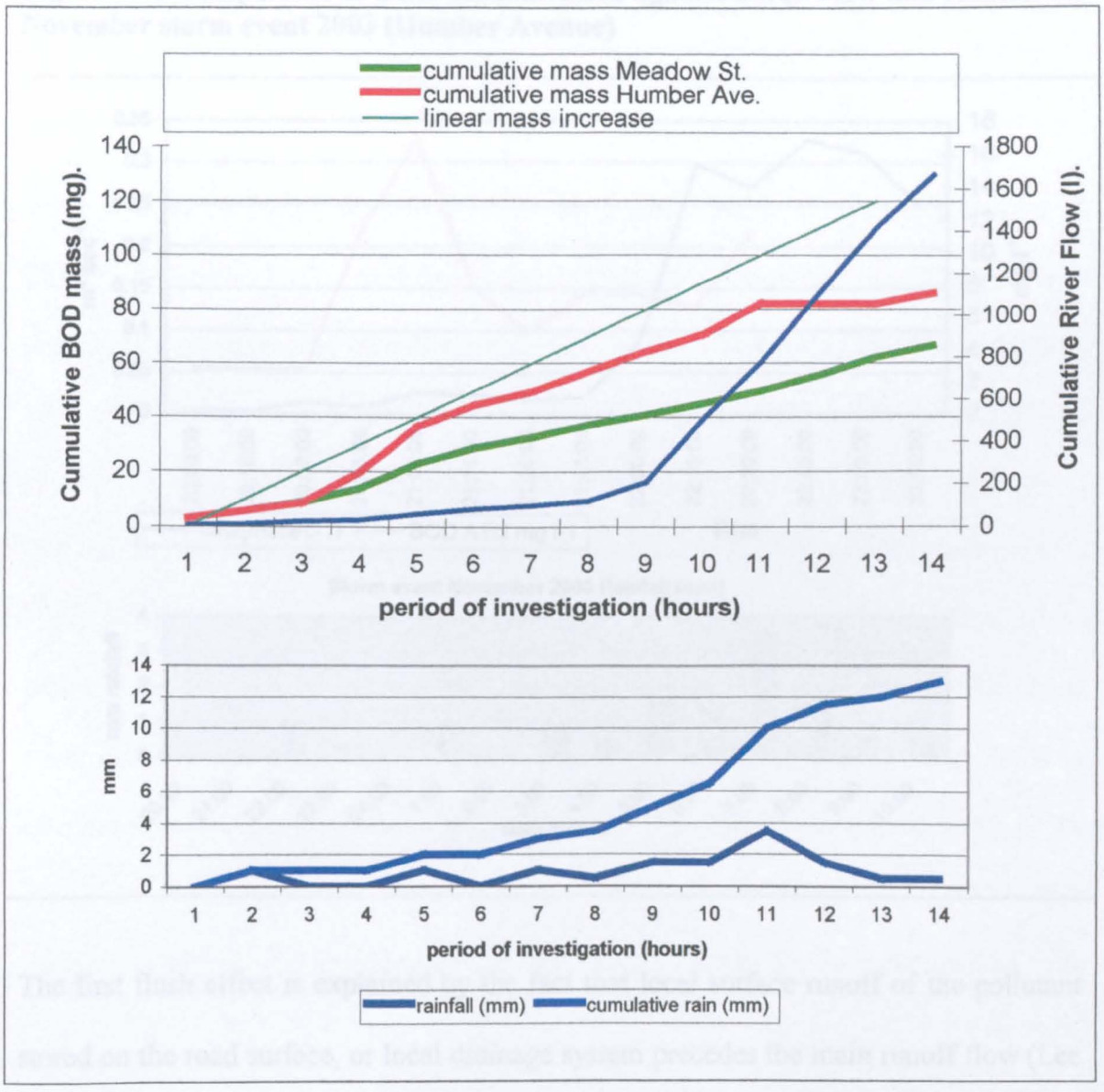
Figure 7.44 Plot of cumulative BOD mass against cumulative river flow at Meadow Street and Humber Avenue during November storm event

The increase in concentration for BOD at both sites during the initial sporadic rainfall period, with a minimal increase in river flow, resulted in cumulative mass BOD values above the linear growth line initially, with a reduced impact during the peak rainfall period. The results were not normalised against other events (Lee *et al.*, 2004) as only one storm event was investigated during 2003, to represent the current position.

Sansalone and Buchberger (1997) suggested that if a cumulative mass curve is plotted for an event that exceeds the cumulative runoff volume curve, a first flush effect has been demonstrated (Section 2.2.1). If cumulative mass for BOD in the River Sherbourne at Meadow Street and Humber Avenue is plotted on the same graph as cumulative river flow, the cumulative mass curve initially exceeds the cumulative river flow curve at both sites, as shown in Figure 7.45. This positive result, based on concentration values alone, appears to demonstrate that a first flush of pollutant had occurred during the November 2003 storm event. During the peak rainfall period following the initial sporadic rain, the peak concentrations for each parameter were reduced.

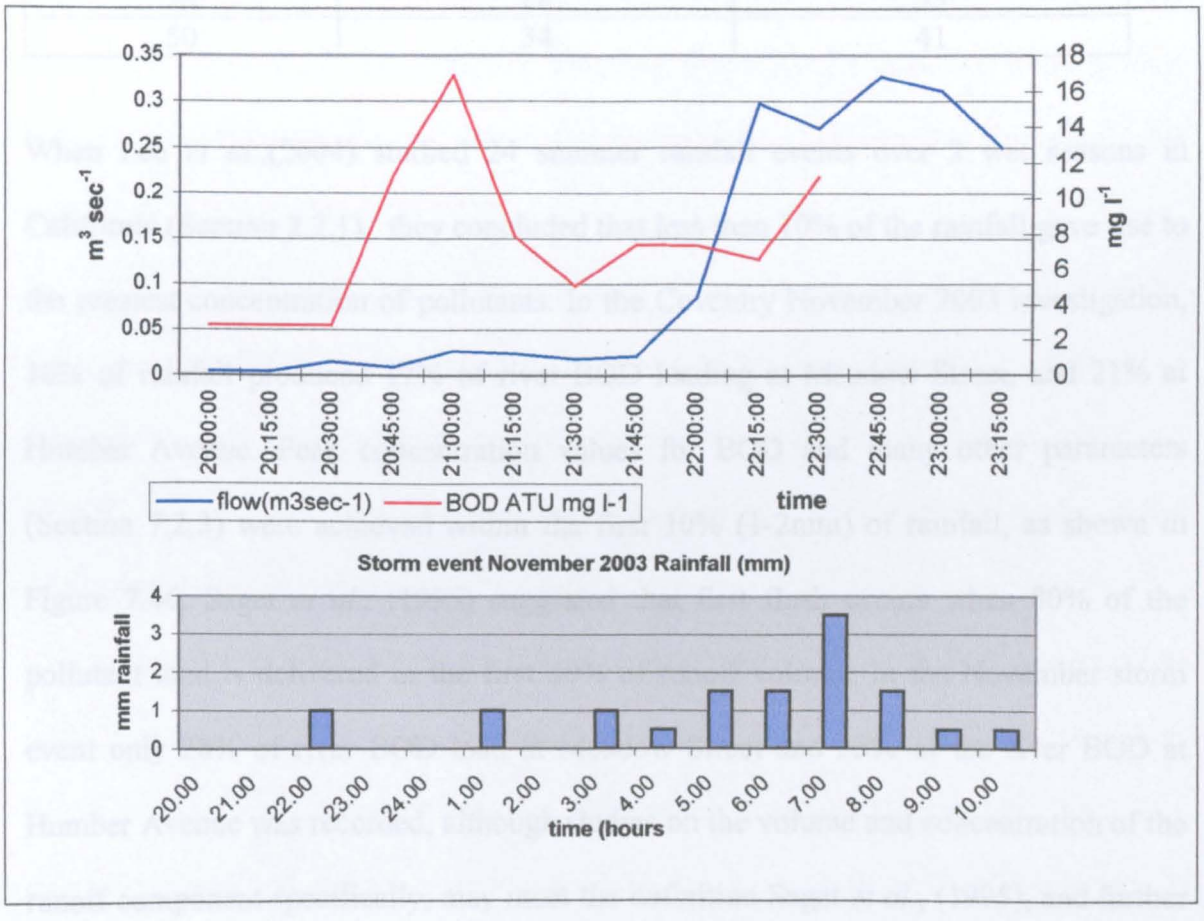
The higher concentrations identified, downstream of the city at Humber Avenue, in table 7.17 and Figure 7.45 suggest that the source of the pollutants may have been as a result street dusts being washed off impervious areas (Mulcahy, 1990; Bannerman *et al,* 1993; Choe *et al.,* 2002; Charlesworth and Lees, 1999) within the inner city area, as shown in Figure 2.2, but could also have arisen from deposited pollutants undergoing transformation and transport during the storm event, in the drainage systems (Deletic, 1998) and culverted watercourses feeding to the River Sherbourne in the culverted city centre Section (Figure 4.5).

Figure 7.45 Cumulative mass curves for BOD, river flow and rainfall, at Meadow Street and Humber Avenue during the November 2003 storm event.



As discussed in Section 2.2.1, and shown in Figure 2.1 (from Laws, 1993), Choe *et al.*, (2002) identified that the concentrations of most pollutants in urban runoff increased with runoff at an early stage of rainfall, and that peak concentrations were reached prior to peak runoff, at most sampling sites. This phenomenon is reported to be more important when the watershed is small and contains mostly impervious surfaces (Lee and Bang, 2000), as is the case with drainage to the culverted stretch of the River Sherbourne. This is demonstrated for the November storm event by the fact that local rainfall and pollutant concentrations peaked before river levels increased markedly, as shown in Figure 7.46.

Figure 7.46 Comparison of BOD concentration against River Flow and rainfall for November storm event 2003 (Humber Avenue)



The first flush effect is explained by the fact that local surface runoff of the pollutant stored on the road surface, or local drainage system precedes the main runoff flow (Lee

and Bang, 2000). Figure 7.46 shows an almost identical result to those identified by Choe *et al.*, (2002), as shown in Figure 2.1. A similar pollutant concentration profile was determined for most other parameters monitored, including heavy metals, and at both sites, as shown in Section 7.2.3 and Appendix 9.

Figures 7.45 and 7.5 also identify that during the November storm event, the BOD load in the river was distributed across the rainfall event as shown in table 7.18.

Table 7.18: Distribution of river BOD loadings – November 2003 storm

Percentage of rainfall during event (%)	Percentage of river BOD Meadow Street (%)	Percentage of river BOD Humber Avenue (%)
10	17	21
25	25	29
30	28	33
50	34	41

When Lee *et al.*,(2004) studied 24 summer rainfall events over 2 wet seasons in California (Section 2.2.1), they concluded that less than 10% of the rainfall gave rise to the greatest concentration of pollutants. In the Coventry November 2003 investigation, 10% of rainfall produced 17% of river BOD loading at Meadow Street, and 21% at Humber Avenue. Peak concentration values for BOD and many other parameters (Section 7.2.3) were achieved within the first 10% (1-2mm) of rainfall, as shown in Figure 7.46. Saget *et al.*, (1995) suggested that first flush occurs when 80% of the pollutant load is delivered in the first 30% of runoff volume. In the November storm event only 28% of river BOD load at Meadow Street and 33% of the river BOD at Humber Avenue was recorded, although studies on the volume and concentration of the runoff component specifically, may meet the definition Saget *et al.*, (1995), and further research is suggested. Nevertheless, the concentration peaks for most parameters were

identified during the initial rainfall period and exceeded in each case (Section 7.2.3) concentration peaks recorded during the subsequent heavy rainfall.

7.3.4 Sampling frequencies

The first hypothesis, in Section 1.4, suggests that occasional spot sampling of watercourses, as carried out under the General Quality Assessment monitoring scheme (Section 2.4.2) does not give a true picture of the variability of water quality in an urban watercourse such as the River Sowe catchment, and that intermittent discharges in an inner city environment could be missed. It further suggests that the use of continuous monitors can give an accurate representation of quality, and assist in the detection and removal of the polluting intermittent sources. Arising from this hypothesis, objective 4 (Section 1.5) determines the optimum sampling frequency for assessing water quality. The success, or otherwise, of this research in meeting objecting 4 in testing this hypothesis, is discussed in Chapter 8.

As discussed in Section 2.4.2, the frequency of sampling controlled waters (Water Resources Act, 1991) by the regulatory bodies is under constant review, and has been periodically reduced as an efficiency measure. Savings made currently may well be targeted towards future monitoring needs, on a more holistic basis, for the Water Framework Directive, as discussed in Section 2.6.

As a measure of whether reductions in sampling frequency in a catchment susceptible to urban runoff can cause significant errors in an assessment of water quality, the data used for statistical analysis recorded from the storm event monitored in November 2003, was sequentially reduced and analysed (Tables 7.18 and 7.19), to determine whether mean, median, 95 percentile, 90 percentile, 10 percentile and 5 percentile results differed significantly, when the number of results (n) was reduced. The values were identified as

being key indicators of quality standards, for measurements (Environment Agency, 2003) carried out by regulatory bodies under the existing legislation, as detailed in Section 2.4.

The tables identify that assessment and reporting of sanitary determinands and heavy metals results can change markedly when the number of measurements is reduced, with some determinands measured in the November 2003 storm event, affected more than others. The values for continuously monitored ammonium were particularly affected, with mean, median, 95 and 90 percentile figures are all reduced from 0.88 mg l^{-1} (mean) and 0.1 mg l^{-1} (others) to 0 mg l^{-1}. The results for upstream and downstream BOD were changed markedly when reducing 14 samples to 1, during the single storm event. Upstream and downstream mean values of 4.76 mg l^{-1} and 8.04 mg l^{-1} respectively, were reduced to 2.85 mg l^{-1}, and more significantly, the 90 percentile values, which are used for defining river class under the GQA scheme (Section2.4.2), were reduced from 7.86 mg l^{-1} and 15.82 mg l^{-1} respectively, to just 2.85 mg l^{-1}. If routine GQA samples results were as variable as this, due to intermittent discharges or sampled storm events, and were similarly reduced in number with the same effect, the classification for the sampled watercourse would change from Bad (below Class E), to Good (Class B).

Heavy metals results are similarly affected, with mean Pb results for Meadow Street and Humber Avenue reduced from 10.71 mg l^{-1} and 24.98 mg l^{-1} respectively, to 0.79 mg l^{-1} and 2.94 mg l^{-1}, after reducing the number of samples from 14 to 1 during a single storm event. The Humber Avenue 95 percentile value for Zn, as used in the River Ecosystem (RE) Classification system (table 2.9), was reduced by the same order, from 226 mg l^{-1} to 22.9 mg l^{-1}. The 5 percentile value for pH as used in the RE classification system as a lower limit, was increased for continuous monitoring, from 7.39 to 7.75 when reducing

Table 7.19 Summary Table showing impact of reducing number of results (n) on quality reporting.November 2003 storm.

	number of sample/ monitor results (n)	US NH4+N mg l-1 continuous	US NH4+N mg l-1 sampled	DS NH4+N mg l-1 sampled	US BOD mg l-1 sampled	DS BOD mg l-1 sampled	US DO % saturation continuous	US pH continuous	US pH sampled	DS pH sampled	US SS mg l-1 sampled	DS SS mg l-1 sampled	US ortho-P mg l-1 sampled	DS ortho-P mg l-1 sampled
Mean	14/56	0.88	<0.5	<0.5	4.76	8.04	108.14	7.62	7.914	7.921	55.43	103.07	<0.5	<0.5
	14/14	0.086	<0.5	<0.5	4.76	8.04	107.67	7.63	7.914	7.921	55.43	103.07	<0.5	
	5	0.08	<0.5	<0.5	4.56	7.54	108.42	7.63	7.92	7.92	61.2	94.6	<0.5	<0.5
	3	0.67	<0.5	<0.5	4.47	6.61	108.87	7.6	7.933	7.933	64.33	98.67	<0.5	<0.5
	1	0	<0.5	<0.5	2.85	2.85	103.7	7.75	8	8.1	9	4	<0.5	<0.5
Median	14/56	0.1	<0.5	<0.5	4.47	7.37	107.4	7.65	7.9	7.9	50.5	81	<0.5	<0.5
	14/14	0.1	<0.5	<0.5	4.76	8.04	106.5	7.66	7.9	7.9	50.5	81	<0.5	<0.5
	5	0.1	<0.5	<0.5	4.33	6.58	105.3	7.64	7.9	7.9	52	73	<0.5	<0.5
	3	0.1	<0.5	<0.5	3.87	5.07	105.3	7.64	7.9	7.9	41	49	<0.5	<0.5
	1	0	<0.5	<0.5	2.85	2.85	103.7	7.75	8	8.1	9	4	<0.5	<0.5
95 percentile	14/56	0.1	<0.5	<0.5	9.03	16.9	117.145	7.75	8	8.1	143	255	<0.5	<0.5
	14/14	0.1	<0.5	<0.5	9.03	16.9	117.6	7.75	8	8.1	143	255	<0.5	<0.5
	5	0.1	<0.5	<0.5	6.69	11.9	117.6	7.75	8	8.1	143	243	<0.5	<0.5
	3	0.1	<0.5	<0.5	6.69	11.9	117.6	7.75	8	8.1	143	243	<0.5	<0.5
	1	0	<0.5	<0.5	2.85	2.85	103.7	7.75	8	8.1	9	4	<0.5	<0.5
90 percentile	14/56	0.1	<0.5	<0.5	7.86	15.82	116.7	7.75	8	8.1	116.5	249	<0.5	<0.5
	14/14	0.1	<0.5	<0.5	7.86	15.82	117.2	7.75	8	8.1	116.5	249	<0.5	<0.5
	5	0.1	<0.5	<0.5	6.69	11.9	117.6	7.75	8	8.1	143	243	<0.5	<0.5
	3	0.1	<0.5	<0.5	6.89	11.9	117.6	7.75	8	8.1	143	243	<0.5	<0.5
	1	0	<0.5	<0.5	2.85	2.85	103.7	7.75	8	8.1	9	4	<0.5	<0.5
10 percentile	14/56	0	<0.5	<0.5	2.85	2.85	99.2	7.42	7.85	7.8	6.5	6.5	<0.5	<0.5
	14/14	0	<0.5	<0.5	2.85	2.85	97.8	7.41	7.85	7.8	6.5	6.5	<0.5	<0.5
	5	0	<0.5	<0.5	2.85	2.85	101.7	7.42	7.9	7.8	9	4	<0.5	<0.5
	3	0	<0.5	<0.5	2.85	2.85	103.7	7.42	7.9	7.8	9	4	<0.5	<0.5
	1	0	<0.5	<0.5	2.85	2.85	103.7	7.75	8	8.1	9	4	<0.5	<0.5
05 percentile	14/56	0	<0.5	<0.5	2.85	2.85	96.57	7.39	7.8	7.8	4	4	<0.5	<0.5
	14/14	0	<0.5	<0.5	2.85	2.85	96	7.4	7.8	7.8	4	4	<0.5	<0.5
	5	0	<0.5	<0.5	2.85	2.85	101.7	7.42	7.9	7.8	9	4	<0.5	<0.5
	3	0	<0.5	<0.5	2.85	2.85	103.7	7.42	7.9	7.8	9	4	<0.5	<0.5
	1	0	<0.5	<0.5	2.85	2.85	103.7	7.75	8	8.1	9	4	<0.5	<0.5

Table 7.20 Summary Table showing impact of reducing number of results (n) on quality reporting.November 2003 storm.

	number of sample results (n)	US Cd µg l-1 sampled	DS Cd µg l-1 sampled	US Cr µg l-1 sampled	DS Cr µg l-1 sampled	US Cu µg l-1 sampled	DS Cu µg l-1 sampled	US Pb µg l-1 sampled	DS Pb µg l-1 sampled	US Zn µg l-1 sampled	DS Zn µg l-1 sampled	US Ni µg l-1 sampled	DS Ni µg l-1 sampled
Mean	14	0.155	0.243	1.75	4.16	10.65	24.98	10.71	24.65	51.24	122.9	<5	<5
	5	0.121	0.279	1.65	3.67	9.59	23.94	9.67	22.91	44.02	126.2	<5	<5
	3	0.117	0.228	1.433	3.71	7.96	20.01	8.197	19.81	34.8	110.63	<5	<5
	1	0.1	0.1	0.5	1.54	2.61	4.93	0.792	2.94	11.3	22.9	<5	<5
Median	14	0.12	0.527	1.78	4.41	11.4	28.2	11.85	28.6	47.7	128	<5	<5
	5	0.008	0.324	1.75	3.49	11.4	21.7	11.8	19.2	45.6	116	<5	<5
	3	0.104	0.219	1.7	3.62	9.36	21.7	11.7	19.2	36.5	116	<5	<5
	1	0.1	0.1	0.5	1.54	2.61	4.93	0.792	2.94	11.3	22.9	<5	<5
95 percentile	14	0.1	0.1	2.94	6.71	18.2	44.6	19.5	41.5	107	226	<5	<5
	5	0.148	0.389	2.19	6.71	12.7	40.4	12.1	37.3	70.1	216	<5	<5
	3	0.148	0.1	2.1	5.98	11.9	33.4	12.1	37.3	56.6	193	<5	<5
	1	0.1	0.1	0.5	1.54	2.61	4.93	0.792	2.94	11.3	22.9	<5	<5
05 percentile	14	0.45	0.389	0.5	1.36	2.5	4.19	0.767	1.67	10.2	19.1	<5	<5
	5	0.1	0.1	0.5	1.36	2.61	4.93	0.792	2.94	11.3	22.9	<5	<5
	3	0.1	0.365	0.5	1.54	2.61	4.93	0.792	2.94	11.3	22.9	<5	<5
	1	0.1	0.1	0.5	1.54	2.61	4.93	0.792	2.94	11.3	22.9	<5	<5
Key to Tables 7.18 and 7.19 : US upstream DS downstream									single result				

readings from 56 to 1, and for sampling from 7.8 to 8.1, when reducing samples from 14 to 1. These pH results have no impact on RE potential in this case, but in a poor quality urban stream; a reduction in sampling frequency could be significant in meeting the appropriate criteria for pH.

Another significant impact on results identified in Table 7.19 is for SS; when n=1, the sample, randomly chosen by sequential reduction of results, reports the SS concentration as 9 mg l^{-1}, upstream of the city centre and 4 mg l^{-1} downstream of the city centre, whereas, if n= 14, the results for upstream of the city are less than downstream, with 90 percentiles of 116.5 mg l^{-1} and 249 mg l^{-1} respectively. The inference, using the reduced sampling frequency, that the upstream site was more polluted during the storm event is totally false, as can be demonstrated when the full range of samples for SS are analysed, and when the results for the other parameters are examined, in Appendix 9.

Table 7.19 also demonstrates that continuously measured parameters such as ammonium and pH results give slightly different results, when compared to sample results for this storm event, with 56 readings being compared to 14 one-hour composites. Ammonium concentrations were recorded that were below the level of detection for laboratory analysis, therefore giving a more accurate representation of the variability of this parameter in storm conditions. The sampled results were all below the detection limit at <0.5 mg l^{-1}. Statistical analysis of pH results recorded by the continuous monitor upstream of the city, indicates that the levels were consistently lower than sample pH. This could be due to the more accurate representation of using 56 readings, as discussed above, but may also be due to the sample reaching equilibrium (Section 7.2.3) in the sample portions during transport to the laboratory, prior to determination of pH.

In general the higher the number of results for each determinand, the more accurate the consideration of overall quality was, and the use of continuous monitors captured

intermittent discharges (resulting in pollutant peaks), which occasional routine sampling (within normal 9 to 5 working hours), would not identify. Storm events (depending on when spot samples are taken within them), can significantly affect quality assessment, and this should be considered in monitoring areas affected by urban runoff.

7.4 Summary – Phase 3

Generally the post–remedial research phase showed an improvement in water quality in the River Sherbourne as a result of addressing the Albany Road problem (Section 3.5), and removal of a number of misconnections and illegal discharges identified in the culverted feeder streams. The use of improved water quality monitors and calibration software generally gave a consistently good level of results for the final 17 runs, including the 3 featured investigations undertaken in 2003. Problems of vandalism, theft and storm debris still had an impact on some investigations, including the November 2003 storm event, but it was generally possible to leave the equipment in place for extended periods, with very little resource requirement.

This methodology (Chapter 4) facilitated a good representation of the impact of many rainfall events, with varied intensity and different seasonal components. The degree of correlation between parameters investigated in the different runs was much higher in the Phase 3 (tables 7.3 to 7.5), with general trends more consistent, as shown in table7.6. Where trends were occasionally reversed for specific parameter relationships, the diverse nature and magnitude of illegal intermittent trade and domestic discharges into the River Sherbourne culvert and feeder drainage systems under the influence of seasonal or specific rainfall conditions (Lee *et al.*, 2004) may have been responsible. For example, where pH increased during some storm events at Meadow Street, this may have been due to the impact of Albany road CSOs, which can deliver intermittent trade

effluent drainage from a small alkaline pine-stripping operation nearby, to the watercourse (Section 3.5). This does not necessarily identify that this method of investigation is flawed, as the majority of parameters showed significant results, (with a high degree of either positive or negative correlations identified for rainfall events during 80% of the runs), but points to the large number of potential pollutants (Novotny and Olem, 1974; Ellis, 1989), and flow profiles (Lee and Bang, 2000) that can impact on urban drainage, and also to the age, size and complexity of the drainage system covered. Other factors such as traffic density, street cleaning frequency and antecedent dry periods (which would have different values for each run and season) would also play a part in contributing to the variability in the results (Sartor *et al.*, 1974; Ellis, 1979, Van Hassel *et al.*, 1980, Hares and Ward, 1999).

Using Spearman's rank correlation to identify correlation between different parameters, and the same parameter at different sites (or under different environmental conditions), was very useful in establishing the relationship, if any, between different pollutants. The large number of investigations could then be analysed to check for consistency in the results, and identify individual measurements or events that were extraordinary. The results identify that even with such a large number of events monitored, the majority of investigative runs can show a particular trend in the relationship between two parameters, with highly significant results recorded. This information can be used to identify how trends have changed over time, according to the nature of pollutants entering the River Sherbourne in the Phases 2 and 3 of this research, and suggest a model for trends in future storm events (Chapter 8). Such results would not have been achievable using traditional sampling methods, at current sampling frequencies, for water quality determination under the GQA monitoring scheme (Section 2.4.2).

Where the number of recorded results obtained for a particular parameter was small, perhaps due to concentrations being below the detection level, the correlation coefficients are not reliable, and highly significant results can easily be reported during statistical analysis. Such varied results were obtained during sampling for Ni, ortho-phosphate and ammonium levels, but where occasional results were recorded, particularly during peak pollutant levels during some storm events, the data is presented for comparison, and consideration of potential relationships with other parameters at these times. Section 7.3.3 considered pollutant loads in the river and identified that a peak in pollutant concentrations ahead of peaking river levels, particularly for BOD and most heavy metals, was recorded during the featured storm events for 2001 and 2003. In comparison, the dryweather investigation showed no significant pollutant peaks, and diurnal rhythm for DO and pH were consistent with expectations for dryweather in a river with a high level of algal activity, as shown in Figures 6.3 to 6.7, and Figure 7.3. The results were consistent with the findings of other authors (Lee and Bang, 2000; Lee *et al.*, (2000); Bannerman *et al.*, 1993; Choe *et al.* 2002), as discussed in Section 7.3.3, and Chapter 8. An examination of the impact of reducing sampling frequencies on water quality assessment in Section 7.3.4 identified that the classification of watercourses could be significantly affected if the 36 samples, currently used for production of the 3-year rolling average of results used for GQA monitoring (Environment Agency, 2003), as discussed in Section 2.4.2, was reduced further. The use of concentrated multiple sampling runs and continuous monitors, gave a good representation of the variability and complex nature of urban runoff (Field *et al.*, 1982; Novotny and Olem, 1994; Bang *et al.*, 1997; Lee and Bang, 2000; Ellis *et al*, 1982), during rainfall events in Coventry. The results obtained, though often intermittent or of short duration, sometimes fall outside of the reported water quality data and could explain some aspects of why

biological assessment is often worse than chemical findings for the same site, as shown in Figures 3.5 and 3.6. Toxicological standards, such as the Fundamental Intermittent Standards (FR/CL 0002. FWR, 1994), described in Section 2.5.1, are better addressed using targeted intensive monitoring during rainfall events in urban areas using this methodology.

Chapter 8 will discuss the findings of this research in relation to the Hypotheses suggested in Section 1.4, and the five objectives identified in Section 1.5. A simple model for the River Sherbourne to identify likely trends for different pollutants during a storm event will be presented, and likely pollutant sources, implications for the future and suggested future research, will be considered.

Chapter 8. Interpretation and discussion of the results

Introduction

This chapter summarises research findings related to the 3 phases of investigation identified in Section 4.2, the three hypotheses suggested in Section 1.4 and the 5 objectives outlined in Section 1.5. It will assess whether the use of continuous monitors is an efficient and cost effective method for determining the presence of intermittent illegal discharges in open watercourses (Section 8.1.2) and in the less conventional research area of culverts and surface water systems suspected to be contaminated by industrial and domestic misconnections (Section 8.1.1). Section 8.1.3 considers whether traditional methods of water quality assessment give results that are representative of the water quality of the River Sherbourne, or whether the use of continuous monitors will present a more accurate picture.

In the process of undertaking this research, continuous monitoring and discrete sample analysis determined the pollutants present in the River Sherbourne, and a comparison was made of urban storm and dry weather conditions, at monitoring points upstream and downstream of the culverted city centre watercourse over a number of years. Initial quality findings and improvements (or otherwise) in the water quality of the River Sowe catchment, following proactive monitoring and enforcement as a result of this research, are considered with respect to the objectives given.

Possible sources of the contaminants remaining are outlined in Section 8.2. The original hypotheses, as given in Section 1.4, are tested in Section 8.3. Future pollution problems, monitoring regimes, and suggestions for further research and water quality assessment, are considered in Section 8.4.

8.1 Summary in relation to research Aims and Objectives

This research was carried out in three phases, and the results, with respect to the aims and objectives identified in Chapter 1, are discussed as follows:

8.1.1 Phase 1 Investigation into the River Sherbourne and River Sowe culverts.

This section outlines the findings of the identification and investigation of polluted underground drainage systems contaminated by intermittent and illegal industrial and domestic discharges. This research will address pollutant inputs to the culverts of the River Sowe catchment, which would not have been specifically identified by monitoring upstream and downstream of the culverted River Sherbourne during Phase 2. This was achieved by the introduction of continuous monitors into the minor river culverts and extensive surface water drainage systems. Objectives 1 and 2 are considered (Section 1.5).

8.1.2 Phase 2 Investigation of the River Sherbourne before remediation of the storm overflow problem at Albany Road.

This section discusses the determination of river water quality in the culverted section of the River Sherbourne impacted by six unsatisfactory combined sewer overflows at Albany Road, upstream of the culverted stretch. Objectives 1 and 2 and 3 are considered (Section 1.5).

8.1.3 Phase 3, Post remedial data collection, October 2000 to November 2003

The determination of river water quality in the River Sherbourne following remediation of the combined sewer overflow problem at Albany Road (Phase 2), and intermittent pollution problems in the feeder culverts and surface drainage systems, investigated in Phase 1. Objectives 3, 4 and 5 (Section 1.5) are considered. The three hypotheses (Section 1.4) are tested in Section 8.3.

8.1.1 Phase 1 Investigation into the River Sherbourne and River Sowe culverts

The first phase involved the use of continuous monitors to identify which culverts and surface water systems were most at risk of contamination. The investigation met two research objectives, 1 and 2, as detailed below.

Objective 1
To investigate the nature and impact of storm water runoff from the City of Coventry and River Sherbourne and River Sowe catchments and identify the sewerage systems which can contribute to a marked deterioration in receiving waters following storm events.

The aims of objective 1 were met during this early phase by the use of the continuous monitors, which proved very successful in identifying which culverts were subject to major pollution problems. The early investigation work in open watercourses across the city of Coventry, and subsequently in the extensive system of culverted watercourses, led to the removal of a significant number of illegal foul sewer overflows, industrial and commercial discharges, and misconnections from domestic foul sewer systems, as discussed in Chapter 5. The use of continuous monitors, placed in surface water drainage systems and small culverted watercourses, gave an insight into the variability of water quality in urban drainage systems. By revealing specific areas of contamination, the research not only reduced the manpower required to investigate the problem, but actually made the process of discharge identification and removal on such an extensive system viable to the extent that the Drainage Authority and Water Company could assist on demand, without extraordinary funding or resource allocation.

The monitoring determined that where a drainage system was unpolluted by misconnections and illegal trade effluents, there was generally a consistent quality, in

excess of GQA class C (Environment Agency, 1997), as discussed in Section 2.4.2, with only minor peaks in conductivity and ammonium levels arising from road runoff and the discharge of road gulleys in the immediate vicinity. This methodology (Figure 4.1) allowed an initial assessment of all of the smaller watercourses and culverts draining to the Rivers Sowe and Sherbourne, discounting the majority from further intensive monitoring, so as to concentrate on the priority areas, in terms of unknown pollution sources, and intermittent contamination. Whether a specific catchment was investigated further using continuous monitors was dependent on whether the quality data showed contaminants present, and that they were significant enough to identify the location and nature of a specific source (Section 4.3).

The determinands monitored in Phase 1 of the study to show the presence of organic contamination were ammonium (total ammonia), DO saturation, pH and specific conductivity. These parameters were chosen because they are important indicators of water pollution (Environment Agency, 2003; Klein, 1972; Tebbutt, 1977), used in the General Quality Assessment (GQA) programme (Environment Agency, 2003), as discussed in Sections 2.4.2, 3.3 and Table 2.7. These parameters were compared during rainfall periods, and in culverts showing physical signs of contamination (solids, faeces, paper etc.), against outfall and river channel concentrations reported during periods of dry weather as a benchmark, and against water quality criteria and recorded routine GQA data (Environment Agency WIMS data records, 1996 – 2003).

Generally it was found that a foul sewer overflow discharging to a culverted watercourse gave rise to an increase in ammonia concentration (Klein, 1972; Montague and Luker, 1994) and specific conductivity, and a decrease in pH and DO saturation (Mason, 1996; Gromaire *et al.*, 2001) as discussed in Section 2.3.1. The pH did rise in some instances (Appendix 3.7); particularly when the source of sewage contamination was continuous, or

close to the monitoring point, and contained cleaning chemicals, alkaline industrial effluents or domestic wastewater. The observations followed expectations based on previous routine monitoring (Appendix 4) and literature reviews (Mason, 1996; Klein, 1972; WRc/UC, 2973, 1998; Murrell *et al.*, 1998), with ammonium concentrations of up to 18 mg l^{-1}, 36 mg l^{-1} and 17 mg l^{-1}, recorded in the Swan Lane, Springfield Brook and Hall Brook culverts respectively.

The results from continuous monitoring gave a clearer indication of the location of intermittent discharges within the drainage systems, and the severity of pollution, in terms of the maximum and mean concentrations involved and the duration of the discharges, as discussed in Section 5.2.4. Identifying ammonium peaks relating to rainfall events and as regular peaks during dry weather in the results consistently led to the discovery of illegal misconnections, storm overflows, and trade effluent discharges. The monitors generally gave consistent results for the same investigation run at different locations, as demonstrated in Appendices 1,2 and 3, and trends during rainfall events, (such as a decrease in pH), were repeated in later observations on the River Sherbourne culvert in Phases 2 and 3. In summary, the use of continuous monitors in an enclosed environment (by an experienced operator, well versed in calibration and maintenance of the equipment), can be very successful in identifying the presence and location of intermittent and hidden pollution sources, which can then be verified by using drain tracers and CCTV for removal from the drainage system. Such intensive investigations subsequently lead to an improvement in water quality, in the receiving watercourse.

Objective 2 has been met by this research by the fact that the level of investigation required to address the intermittent pollution problem in Coventry's drainage system using conventional spot sampling techniques, would not have been financially viable, and the data would not have been sufficiently site-specific to enlist the immediate and

full cooperation of the drainage authority, in locating and remediating the many pollution problems identified.

Objective 2

To investigate the use of multiple probe continuous monitors in urban surface water drainage systems and culverted watercourses, and determine whether this method can be cost-effective in identifying urban runoff problems arising from urban runoff, combined sewer overflows and industrial operations.

The maintenance of continuous monitors became more straightforward by gaining familiarity with the deployment, capabilities and limitations of the equipment. The most costly replacement item was the ammonium probe, which required renewal every 6 months (see Section 4.2.2). During the monitoring periods for Phase 1, it was estimated that £10000 per annum was spent on maintaining, replacing and calibrating the 10 continuous water quality monitors available. These monitors were used for all water quality monitoring and investigatory or compliance work required by the Environment Agency's Environment Management team, based at Warwick.

To determine whether the use of continuous monitors can be cost effective in an investigation to determine unknown pollution sources the following factors should be considered:

i) Ten continuous water quality monitors cost £10000 per annum for maintenance; therefore one monitor costs £1000 for continuous use over a 12-month period.

ii) The initial cost of purchasing each monitor was not considered in these calculations, as each monitor was purchased to determine compliance breaches for permitted discharges to watercourse and monitoring water quality trends in open watercourses elsewhere. Operational equipment forms part of the 'overheads' component charge

in recharging for Environment Agency operations (similarly the cost of purchasing and maintaining vehicles used by sampling Officers is excluded from the comparison). The current (rechargeable) rate for an Environment Agency Officer's time is £75 per hour (Environment Agency Incident Management System, 1995).

iii) The cost of sanitary analysis (Environment Agency, suite 961) was £34.95 per sample at the time of the monitoring exercises during Phase 1. A single investigation entailing 12 (hourly) samples using an ISCO automatic sampler cost £419.40 in analysis costs alone. In comparison, each reading by a continuous monitor, as shown in Table 8.1 (below), costs £0.207.

iv) The continuous monitors used in this research cannot determine total metal concentration, and samples were taken for laboratory analysis. The total cost for analysis including total metals, per sample was £45.45. In this research metal analysis was requested to identify what pollutants are present during storm events (objective 1) and what potential pollution problems remain (objective 5), after remedial measures have been undertaken to remove polluting sources (Phase 3).

v) The calibration and installation of a continuous water quality monitor (giving 15-minute readings for up to 14 days) requires one operative, where Health and Safety considerations allow. Installation, (and post–sampling removal) of an automatic sampler holding twelve 500ml samples (or more) requires at least 3 operatives.

vi) A continuous monitor can easily fit into a saloon car for transportation, whilst an automatic sampler requires the use of a van or similarly sized vehicle. This enables an experienced operative to install or remove monitoring equipment during the course of their routine duties.

A typical Environment Agency investigation into intermittent pollution on the Hall Brook would be undertaken with samples at approximately five locations, including

upstream of the urban (culverted area) with analysis costs for one set of discrete samples at an approximate total cost of £175, plus Officer (1 day) costs of £600. To gain an indication of the scale and approximate time period of the suspected discharge, would involve the use of an automatic sampler at the outfall taking hourly composite samples for a single period of 12 hours with a total cost of £419.40. The total analysis cost would therefore amount to around £595 for a single days investigation. The cost of deploying three Environment Agency officers to lift manholes for sampling, install and subsequently remove the sampling equipment at the outfall, transport the samples for collection and complete the sample input forms would approximate to eight hours for each officer, at a total cost of £1800 excluding transport costs. The total cost for investigating the water quality on the Hall Brook using conventional sampling techniques for a period of 12 hours would therefore be in the region of £2400.

The suspected intermittent discharge may not take place during this time and it is likely that a variation in weather conditions would not occur at a convenient time within the 12-hour period, meaning that the beginning of a storm event could be easily missed during the time it takes to mobilise the resources required for the investigation.

The cost of installing 5 automatic samplers for a period of 12 hours (even if they could be installed and collected within 8 hours using 3 officers) to give an in-depth representation of the variation in water quality over the course of a day or night would be £2097 for sanitary analysis, plus £1800 installation costs, totalling £3897. If this level of monitoring were maintained each day for 12 hours, for a 14-day period, the total cost would be £54,558, which would double to £109,116 for 24-hour coverage.

Alternatively, to undertake a continuous monitoring run with 5 continuous water quality monitors at specific locations in a culverted watercourse or surface water sewer for a period of up to two weeks using two Officers (for lifting manholes) costs £1200

excluding transport. As discussed previously, a continuous monitor costs the Environment Agency £1000 per annum (to maintain in-house, including staff costs). A single monitor used for 14 days therefore costs £38.36 per monitor, or a total cost for 5 monitors of £191.78. The total cost therefore for a 14-day investigation, which gives continuous data day and night, and in storm and dry-weather conditions, is £1391.78. Table 8.1 summarises the comparative costs of each investigation:

Table 8.1 Comparative hypothetical costs for sampling and continuous monitoring during investigation of surface water sewer/ culverted watercourse (5 sites)

	No. of people	People costs £	Equipment deployed	Equipment costs £	Total costs £	No. of readings	Period monitored	Comments
A	1	600 1day	5X spot samples	Analysis @ 175	775	5	1 off	Snapshot at time of sampling. Cheap
B	3	1800	5X spot samples + 12 autosamples	Analysis @ 595	2400	17	12 hours 1 site	Some indication of time occurring 1 day
C	3	1800	5X autosamplers for 1 day	Analysis @ 2097	3897	60	12 hours 5 sites	Area and time identified 1 day only
D	3	25200	5X autosamplers for 14 days	Analysis @ 29358	54558	840	14 days @ 12 h d^{-1} 5 sites	Not practicable for laboratory or people
E	6	54400	5X autosamplers for 14 days (continuous)	Analysis @ 58716	113116	1680	14 days @ 24 h d^{-1} 5 sites	Not practicable for laboratory or people
F	2	1200 4h x 2d	5 continuous monitors 14 days	191.78	1391.78	6720	14 days @ 24 h d^{-1} 5 sites	Reading every 15 minutes for period of monitoring (at a cost of 20.7pence per reading)

The saving achieved by using continuous monitoring (option F) is therefore £1028.22 over the reduced level of investigation (option B), and a significant £2505.22 saving compared to the use of 5 automatic samplers strategically situated in the Hall brook Culvert for 12 hours (option C). The saving against a hypothetical investigation, where 5 auto monitors are employed for 12 hours per day for 14 days (option D), is £53166.22, or for 24 hour coverage (option E), £106,332.44.

This hypothetical exercise demonstrates how cost efficient the use of continuous monitors is by experienced operators. The financial savings possible for intensive

monitoring surveys of urban runoff in an extensive drainage system, or on an open watercourse are significant, and fully meet the requirements for objective 2.

8.1.2 Phase 2 Investigation of the River Sherbourne before remediation of the storm overflow problem at Albany Road

During this phase continuous monitors were placed upstream and downstream of the culverted section of the River Sherbourne to determine the impact of six unsatisfactory combined sewer overflows situated in Albany Road, as detailed in Section 3.1. The quality of the watercourse during storm events, and dry-weather periods, was investigated during phase 2 and 3, to determine the contribution to pollution load from the city centre drainage systems, which join the culverted watercourse between the points monitored. This research also met the aims relating to the first part of objective 1 as follows, and objective 2.

Objective 1

To investigate the nature and impact of storm water runoff from the City of Coventry and River Sherbourne and River Sowe catchments and identify the sewerage systems which can contribute to a marked deterioration in receiving waters following storm events.

The results of specific early and pre-remedial continuous monitoring investigations are discussed in detail in Chapter 5, and represented graphically in Appendices 4 and 5. During dry weather investigations, most days, as in the run carried out on 15 March 2000 (Table 6.2 and Appendix 5.3.1), showed no major peaks or troughs for any of the parameters measured, other than as a result of diurnal variation due to algal activity in the watercourse. Continuously monitored ammonium levels showed little variation during dry weather, and sampled ammonium concentrations were below detectable levels at all times,

unless a single intermittent pollution event, misconnection or CSO spill was suspected, as occurred on 16 March, when a suspected trade effluent discharge raised ammonium concentration to 70 mg l^{-1}. Unionised ammonia was not monitored during this phase of the investigation due to probe failure, and it was not determined whether the daily peaks monitored during the early stages of the research (Section 6.1.1) were still present.

During rainfall events however, the continuous monitors demonstrated a significant impact on DO, ammonium, pH and SC data, during early and pre-remedial data collection (Tables 6.1 and 6.2) and sampled results for BOD, SS and total heavy metals were also affected as river levels increased. During early data collection (October 1996 to September 1997), ammonium levels increased to levels of around 4 mg l^{-1}, and diurnal rhythm was disrupted, or lost, for DO and pH, with DO saturation falling to <5% saturation on several occasions, as shown in Table 6.1. Sampled BOD upstream of the city was identified as out of class for the River Sherbourne (class C), as described in Chapter 6. Pre-remedial results (Table 6.2) also showed disruption of natural diurnal rhythms for DO and pH (for periods of up to 6 days), as would be expected following an input of major organic pollution (Mason, 1996; Klein, 1972; WRc/UC, 2973, 1998; Murrell *et al.*, 1998) to the watercourse (see Sections 2.3.1, 3.6 and 6.2), with DO, SC and pH levels falling during rainfall events, and BOD, SS and ammonium concentrations rising to 18 mg l^{-1}, 120 mg l^{-1} and 1.8 mg l^{-1} respectively. Generally, during the early data collection and pre-remedial data collection for Phase 2, DO levels decreased with saturation concentrations of <5%, or even 0%, on more than one occasion, and ammonium concentrations increased above the 90 percentile figure of 1.3 mg l^{-1} for a class C watercourse (Section 2.4.2), with an average of 1.97 mg l^{-1} for early data. Temperature, DO and pH diurnal cycles were disrupted or lost for several days following a storm event, and SS concentrations increased, along with heavy metal content, as discussed in Section

6.2. Sampled results for Cd, Ni and total P were generally below detection limits, and increases in Cu, Zn and Cr were linked with increases in SS. Levels of pH were generally lower upstream of the city than at the downstream monitoring point, though occasionally a major rainfall event would cause an increase in pH at the upstream point only. These events were possibly related to a spill from the unsatisfactory CSOs at Albany Road (Section 3.5) and the alkaline trade effluent component, as discussed in Sections 6.2 and 8.2. The results met objective 1 and 2, by showing that rainfall-related events during Phase 2 had a significant impact on the River Sherbourne, and that the local impact of the Albany Road storm overflows and culverted streams can only be accurately, and cost effectively determined by the use of intensive continuous monitoring and sampling surveys.

The peaks and troughs for all parameters, and the relationships between them would not necessarily have been identified in the monthly General Quality assessment of the watercourse routinely carried out by the Environment Agency (Section 3.3), and information gained during this phase was used to identify that remediation of the Albany Road problem was needed. It also confirmed that investigation of the culverted feeder streams was required to improve the quality of the River Sherbourne, and resulted in the removal of the unsatisfactory combined sewer overflows as discussed in Chapter 3.

An investigation by Severn Trent Water Ltd in 1999 subsequently identified that the initial overspill calculation of one discharge per year was significantly incorrect and estimated instead 15 spills per year from the Albany Road system with a volume of 2300m^3 of untreated storm sewage discharging to the watercourse. The proposal for remediation of the system involved the introduction of one high-level storm relief weir with a carry-forward flow of 850 l s^{-1}, giving an overspill frequency of once per year, with a discharge volume of only 25m^3 of diluted sewage effluent. The Environment

Agency and Severn Trent Water Ltd recognised the need to continue and expand the investigation of culverted feeder streams to remove unknown pollution sources, although no specific funding for this work was identified. The results obtained in this Phase of research identified base levels of pollutants for a comparison with post remedial conditions, as required by objective 3 (Sections 1.5 and 8.1.3).

8.1.3 Phase 3, Post remedial data collection, October 2000 to November 2003

The results for the post-remedial phase show that following the remediation of the Albany Road combined sewage overflow system, the quality of the watercourse has generally improved, when compared to data from Phase 2. Reductions in mean ammonium concentrations and increases in DO percentage saturation were observed during rainfall events as a result of the remediation works, as discussed below.

Phase 3 of the research satisfies objective 3 as follows:

Objective 3

To investigate if the identification and removal of point source pollution will change the impact of urban drainage from the City on receiving watercourses by analysis of a number of storm events monitored upstream and downstream of the City.

The six unsatisfactory storm overflows at Albany Road were replaced with one high level storm relief outfall, at around the end of September 2000, as described in Section 3.5, in conjunction with works to remove a number of illegal storm overflows, misconnections and illegal trade effluents; identified by continuous monitoring in surface water drainage systems during Phase 1, between December 1997 and April 2001 (Chapter 5). During Phase 3 (October 2000 to November 2003), a total of 17 investigative runs were carried out on the culverted city-centre section of the River

Sherbourne, and a comprehensive data set for dry weather and rainfall events was collected. This was used to identify relationships between sites (upstream and downstream of the city centre), between parameters, and to identify the trends in pollutant concentrations during rainfall events. The results of these investigations are discussed in Sections 7.3 to 7.5, and presented in Appendices 6 – 10.

Generally, the results obtained from the runs were consistent, showing a high correlation between results and increases in rainfall or river flows for continuously monitored and sampled investigations (Tables 7.3 to 7.14) with repeated highly significant and significant relationships identified between different parameters and different sites. The large number of investigations, and repeatability of these results, allows a high level of confidence that the trends demonstrated against flow, for specific pollutants, are representative of the River Sherbourne at this location. These trends are identified in response to objective 5 below, as a simplistic model for pollutants during rainfall events in the River Sherbourne.

During Phase 3, the peaks and troughs identified at both sites were generally smaller during most rainfall events, and DO saturation remained higher and more constant than in the previous phase, with routinely recorded as 80-90% saturation, rising to over 100% saturation as a result of algal activity. Ammonium levels were also commonly reduced, as detailed in Table 7.1, with concentrations reaching 1.5 mg l^{-1} during rainfall events. Although natural diurnal variation for DO and pH were disrupted during rainfall events, the resultant water quality remained good with relatively high levels of oxygen saturation and pH levels within acceptable limits. During run 16 (Table 7.1) on 30 April 2001, DO %saturation dropped to zero at Humber Avenue (downstream of the city), and showed a poor recovery after a heavy rainfall event (Appendix 6.9). The high level overflow outfalling just upstream of Meadow Street, may well have been in operation

during this investigation. Meadow Street results showed a greater impact for parameters other than DO, from the storm event, than at Humber Avenue, as discussed in Table 7.1, so it is possible that the downstream monitor was affected by debris collected around the sonde. Total P maintained levels of around 300-400 $\mu g\ l^{-1}$, with dilution from rainfall events recorded. It is likely that the main source of nutrients during Phase 3 is upstream of the city centre, arising from the rural areas around the unsewered Pickford Brook catchment, as shown in Figure 3.2. The pH levels at Meadow Street were generally lower than at Humber Avenue, as discussed in Section 7.3.1, although rainfall events reduced pH levels at both sites by the same degree. During Phase 2, the monitoring results showed an improvement towards September 2000, whilst the unsatisfactory storm overflows were being examined and prepared for replacement, and more illegal and intermittent discharges were being removed from the smaller culverts and drainage systems. This improvement continued during Phase 3, with final completion of the CSO remediation scheme, and most of the intermittent sources identified and removed, by Summer 2001. A comparison of maximum, minimum and mean pollutant concentrations for the River Sherbourne between the Phases 2 and 3 of the investigation (Table 7.6) shows a clear improvement in the watercourse during rainfall events.

Maximum, minimum and mean values for three featured investigations for the March 2001 and November 2003 storms and the September 2003 dryweather event against pre-remedial data for the River Sherbourne as discussed in Chapter 7, are given in Table 7.16. Mean concentrations for ammonium are reduced, and DO concentrations are higher during the later investigations.

Chapter 7 reported that there were still peaks remaining for contaminants such as heavy metals and SS, which can be identified with urban runoff during wet weather, and pollutant levels generally are higher downstream of the culvert in the 2003 results, as

shown in Table 7.15. Although there are probably still some illegal and intermittent sources discharging to the watercourse through urban drainage systems, the removal of the known unsatisfactory point sources and the identification and remediation of other pollution sources (illegal storm overflows, cross connections between foul and surface water sewers, and misconnections of domestic and industrial waste waters) has resulted in a reduced deleterious impact on the watercourse from urban runoff, and water quality, in terms of chemistry and biological monitoring below the city centre has improved as summarised in Tables 3.1 and 3.2, and Figures 3.4 to 3.6.

The River Sherbourne now meets current water quality standards for a Class C watercourse (Table 2.7), as discussed in Section 3.3, and the River Avon has progressively improved with summer data for continuous monitoring showing improved DO percentage saturation levels and a consistently lower concentration of ammonium, as discussed in Section 3.9 and shown in Figures 3.9 and 3.10.

The removal of organic pollution from illegal sewer overflows, misconnections and trade effluents, and remediation of the CSO problem identified at Albany Road has therefore had a significant beneficial effect on water quality downstream of the investigation area. This investigation has, in determining changes in water quality, trends and priority pollutants in the River Sherbourne upstream and downstream of the contributory drainage systems, therefore met the requirements for objective 3.

Three investigations were featured to represent the improving situation with respect to pollutant concentrations during the post-remedial Phase 3, as shown in Table 7.16. The three, featured investigations for March 2001, September 2003 and November 2003 were examined to meet objectives 4 and 5.

Hypothesis A (Section 1.4) suggests that occasional spot sampling of urban watercourses does not give an accurate representation of chemical water quality. Tables

7.18 and 7.19 identify how the statistical data for a single water quality investigation can change when the frequency of sampling, either by manual sampling or continuous monitor measurement, is progressively reduced.

Objective 4

To determine the optimum frequency for sampling or assessing water quality in an urban environment and specifically the River Sherbourne and River Sowe catchment areas around the City of Coventry.

The data for the storm event in November 2003 was randomly yet progressively reduced, and the results subjected to statistical analysis to determine mean, median and percentile values for all monitoring and sampled data by determinand. The results are discussed in detail in Section 7.3.4, and given in Tables 7.18 and 7.19.

In summary, it was determined that the higher the number of results for each determinand, the more accurate the assessment of overall quality was. Continuously measured parameters such as ammonium and pH results give slightly different results when compared to sample results for the same parameter, with 56 readings being compared to 14 one-hour composites taken during the November 2003 investigation. Continuous monitors recorded Ammonium concentrations that were below the level of detection for laboratory analysis; therefore giving a more accurate representation of the variability of this parameter in storm conditions. The use of continuous monitors also captured intermittent discharges (resulting in pollutant peaks), which occasional routine sampling (within normal 9 to 5 working hours), would not necessarily identify. Storm events, can therefore significantly affect quality assessment, depending on when spot

samples are taken within them, and this should be considered in monitoring catchment areas affected by urban runoff.

The reduction of results for spot samples taken during a single rainfall event, also had an impact on overall assessment of water quality. The results for upstream and downstream BOD were changed markedly when reducing 14 samples to 1, during the single storm event. Upstream and downstream mean BOD values of 4.76 mg l^{-1} and 8.04 mg l^{-1} respectively, were reduced to 2.85 mg l^{-1}; and the BOD 90 percentile values, which are used for defining river class under the GQA scheme (Section 2.4.2), were reduced from 7.86 mg l^{-1} and 15.82 mg l^{-1} respectively, to just 2.85 mg l^{-1}.

If routine GQA samples results were as variable as this, as a result of intermittent discharges or spot samples taken during storm events (and sampling frequencies were similarly or even marginally reduced in number), the classification for the sampled watercourse would change from being assessed as 'Bad' (below Class E), to 'Good' (Class B).

The examples given in Section 7.3.4 give confirmation that spot sampling, particularly at reduced frequencies as described in Section 4.1, does not give an accurate indication of water quality, or consider the extent or significance, of extreme values obtained when sampling rainfall related urban runoff. This information is required for consideration of toxicologically based standards, such as the Fundamental Intermittent Standards (Section 2.5.1), suggested by the Urban Pollution Management methodology (FR/CL 0002. FWR, 1994) It will also be an important consideration in assessing water quality as part of ecological quality, as a more holistic approach to the environment, under the Water Framework Directive (2000/60/EC).

Objective 5

To identify potential pollution problems remaining in urban runoff in the River Sherbourne catchment and consider the implications, if any, against future use of the watercourse and applicable water quality standards.

As identified in Section 8.1.1 and Table 3.2, 60% of the watercourses in Coventry have shown an improvement in water quality, based on monthly sampling data for General Quality Assessment (Environment Agency, 2002). This data relies on monthly spot sampling during daylight hours, and is collated for 36 samples on a three-year rolling programme. The data identifies which classification of watercourse is appropriate, as identified in Table 2.7 (Chapter 2). The minimum DO percentage saturation is expressed as a 10-percentile figure for each class and the maximum concentrations for BOD and total ammonia (NH_4^+N) are expressed as 90 percentiles. The limits relating to GQA (Table 2.7) for BOD, total ammonia and DO are repeated in the River Ecosystem Classification scheme (Table 2.9) based on proposed river usage, but guidelines for dissolved Cu, unionised ammonia, total P and total Zn are expressed as 95 percentiles. As discussed in Chapter 3, the River Sherbourne is not classed as a cyprinid fishery, although the receiving waters of the River Sowe do now support a diverse coarse fish population, and the River Avon is a designated fishery downstream of Warwick (Figure 3.1).

The length of culverted section through the city centre limits the future use of the River Sherbourne culvert at present, but there are proposals by property developers to open some stretches of the culvert in the near future (Coventry C.C. Urban Design Study Final Report 571, 1999), which may make a feature of the watercourse, and improve it's

amenity value within the curtilage of the inner ring road (Figure 2.2). The Rivers Ecosystem limits (Table 2.9), and the Fisheries Directive (78/659/EEC) mandatory and guideline limits (Table 2.10) are therefore useful in guiding local authorities, water planners and environmentalists to make decisions on reasonable and achievable uses of the urban river in comparison with available quality data. The availability of accurate local data is particularly important in this respect (Bannerman *et* al., 1993; Lee and Jones-Lee, 1993; Brezonik, & Stadelmann, 2002). Under the Fisheries Directive (78/659/EEC), the pH limits are identified as 5 percentile and 95 percentile values, with mandatory minimum DO concentration relating to 50% of samples, SS expressed as a mean concentration and the other parameters (total ammonia, BOD, total P, total Zn and dissolved Cu) expressed as 95 percentiles.

The results from the September 2003 dryweather investigation (Section 7.2.2), and the November 2003 storm (Section 7.2.3), identify that the current quality of the river Sherbourne is much improved as discussed for objective 3 above, in comparison to early data (Table 7.16) and, as discussed in Section 7.3, sanitary determinands do not pose any threat to the current GQA and RE classification as a Class C, RE4 watercourse. The relatively high mean BOD concentrations, particularly at Humber Avenue during the storm event, are a matter of concern, as they are only just within UK derogated values, but would fall outside guideline values for cyprinid fisheries under the EC Freshwater Fish Directive (78/659/EEC). As discussed in the last section, the use of continuous monitors during rainfall events has revealed that intermittent standards (section 2.5.1) can still be breached in the River Sherbourne, and that development of the watercourse, even in the slower waters of the River Sowe beyond the confluence (Figure 3.1), as a designated fishery, would not therefore be appropriate at this time.

The heavy metals measured during the November 2003 storm event exceeded the levels found in dry weather as discussed in Section 7.4, but they do not exceed the guideline or mandatory limits for the protection of coarse fish (Table 2.10). The mean, median, 90, 95, 5 and 10 percentile values for sanitary determinands and heavy metal concentrations measured during the November 2003 storm upstream and downstream of the city, are given in Tables 7.18 and 7.19, and are consistent with the findings of other studies relating to urban runoff (Lee and Bang, 2000; Lee *et al.*, (2000); Bannerman *et al.*, 1993; Choe *et al.* 2002), as discussed in sections 7.3.3 and 7.4. All heavy metals showed a concentration peak, or first flush effect (Saget *et al.*, 1995; Lee and Bang, 2000; Forster, 1996; Harrison and Wilson, 1985), during early rainfall after periods of dryweather during the November 2003 rainfall event, and concentrations were generally higher downstream of the city, as shown in Figures 7.4.1 (a-p), and 7.4.2 (a-j).

As discussed in Section 7.2.1iii, only the Cu concentration identified (Figure 7.7) in the 2003 rainfall event investigation gives reason for concern against water quality criteria (Table 2.10). The measurements obtained were for total Cu with concentrations comparable to the limits for the dissolved fraction as specified in the table. It is likely that the dissolved fraction constituted less than the total amount determined, and was therefore within the prescribed guidelines.

Under current legislation, the results for Phase 3 (particularly data recorded during 2003), do not present a risk to water quality standards or future use of the Rivers Sherbourne, Sowe and Avon. Under the Water Framework Directive (2000/60/EC), the urban runoff component is perceived as a risk in not achieving good ecological status, as discussed in Section 3.11, although until the definition of 'good' in this assessment has been qualified, potential compliance is a difficult issue to address, and derogations for the River Sherbourne, as a 'heavily modified watercourse' may apply.

In the early stages of this investigation the poor water quality of the River Sherbourne, and reported failings for compliance against river quality objectives (Environment Agency, 1997), led to consideration of the need for treatment facilities downstream of the city. Introduction of wetlands, sedimentation lakes, and even bubble screens (to aerate the lower reaches of the Rivers Sowe and Avon) were considered by the Environment Agency, although the costs for installation and maintenance would have to be justified by further research. This investigation has identified that improvements in water quality, and the removal of major intermittent pollution sources, has reduced (or even removed), the requirement for these sustainable urban drainage systems (SuDS) to be installed. Similarly, previously held objections to proposals (at planning application stage) for opening polluted culverts as amenity features, in some areas such as Hall Brook and the central River Sherbourne, by local environmental regulators would be less likely as a result, although increasing access to the watercourse may still present some risk to the public, because of bacterial and pathogenic contamination (Section 8.2.4), from rat-infested sewerage systems.

8.2 Possible sources of contamination in the River Sowe catchment

8.2.1 Introduction

Chapter 2 identified that urban runoff is the result of point and non-point sources (Choe *et al*, 2002), and can include precipitation, soil erosion, accumulation and wash off of atmospheric dust and street dirt, fertilisers, pesticides and direct discharge of pollutants into storm sewers (Novotny & Olem, 1994). Urban sediments represent the net effect of urban activities upstream, and as such are predominantly the result of storm water runoff events combined with the deliberate human, or occasional natural, supply of debris to the watercourse (Douglas, 1985). These stormwater sediments are therefore a heterogeneous mixture of particles (Ellis *et al*, 1982), and a city centre location, adjacent

to housing and industry, will provide a complex mixture of sources (Charlesworth & Lees, 1997). The provision of foul and surface water sewerage systems in Coventry (Section 3.4) would suggest that harmful sewage discharges to watercourses would be reduced (Luker and Montague, 1994). However, pollution from misconnections, illegal discharges and storm overflows is a common cause of pollution incidents reported in urban watercourses (Environment Agency, 2003), which had directly contributed to non-compliance against water quality objectives in the urban river stretches of Coventry during the mid 1990s, as described in Sections 3.3, 5.2 and 6.2.

Non-point pollution arising from stormwater runoff is one of the major causes of deterioration in water quality, and the characteristics of urban runoff are more difficult to quantify than those of wastewater (Field *et al.*, 1982; Novotny and Olem, 1994; Bang *et al.*, 1997; Lee and Bang, 2000). The degraded character of urban watercourses, such as the River Sherbourne, results not from one single factor, but from the interaction of a variety of detrimental effects. Runoff from street surfaces can be highly contaminated and pollution concentrations can vary widely according to rainfall intensity, surface properties, particle size, antecedent dry periods and the efficiency with which streets were cleaned (Sartor *et al.*, 1974). Harremoës, (1981) suggested 3 areas to be considered to counter the effects of urban runoff; control at source, improved street cleansing and treatment of runoff.

Best Management Practices, including the use of detention ponds and Sustainable Drainage Systems (SuDS), can be targeted to serve specific problems (for example, at industrial sites and on highways) at a lower cost of construction and maintenance (Bannerman *et* al., 1993; Lee and Jones-Lee, 1993), although, as discussed above, they may no longer be applicable to general drainage problems in the River Sowe catchment. Perdikaki *et al.*, (1999) suggested that where treatment of flows prior to sedimentation is

not possible, future efforts should concentrate on limiting pollutants generated at source. This was the proactive approach taken during this research.

8.2.2 Organic contaminants

Historical and current pollution levels identified in the culverted watercourses of the River Sowe catchment, and more specifically, for the city- centre culvert of the River Sherbourne, are outlined in Sections 5.1, 6.1, 7.1 and 7.3. It is clear from the improvements in water quality identified through each phase (Tables 7.6 and 7.16) that the sanitary determinands (BOD, ammonium and SS) currently present less of a risk to water quality standards than before. The major contribution of these contaminants arose from the unsatisfactory operation of the 6 combined sewer overflows located in Albany Road, which spilled raw (albeit diluted) sewage into the River Sherbourne from the Hope Street outfall (Figure 4.5) at a frequency in excess of the design characteristics (section 3.5). The impact of urban runoff on the watercourse generally increased through the culvert, as the river received drainage from the culverted streams and surface water drainage systems discharging between Meadow Street and Humber Avenue (Figure 4.5). Although pollutant levels are still marginally greater at the downstream monitoring point during rainfall events (Tables 7.8 to 7.16), the removal of illegal and intermittent sewage and trade effluent discharges identified in Phase 1 had a significant effect on reducing contaminant concentrations (objective 3, above), with sampled ammonium concentrations at Humber Avenue below detection levels during the November 2003 rainfall event. Hydrocarbons are frequently seen as iridescence on the River Sherbourne during rainfall events, and occasionally heavier discharges, arising from highway and industrial spillages (or fires), enter the urban watercourses in the River Sowe catchment. Hydrocarbons were not analysed in this research, but it should be identified that most hydrocarbons are degradable, and that 70-75% of hydrocarbons show a strong

attachment for suspended solids (Montague and Luker, 1994), which may be reflected in the results for BOD, COD and DO % saturation, although any hydrocarbon contamination of monitoring equipment or reports of major spillage would have been identified in the results.

8.2.3 Heavy metal contamination

The heavy metal concentrations still showed peaks during rainfall events, and were generally higher at the downstream monitoring point in the River Sherbourne (Humber Avenue), than at Meadow Street, as shown in Figures 7.4.1 (a-p) and 7.4.2 (a-j). Potential sources for heavy metals contributing to urban runoff are from atmospheric pollution (including emissions from the Coventry incinerator), illegal trade effluent discharges and spillages, vehicle use and emissions, roof water runoff, corrosion of buildings and natural soil derived sources, as discussed in Chapter 2. The increase in these parameters during rainfall indicates that urban runoff is contaminated by local sources, and good correlations between SS and Zn, Cr and Cu downstream of the city, suggests that some heavy metals are associated with particulates arising in the city centre environment. Coarse particles will not be carried in suspension even in fast river flows, but are transported by rolling along the riverbed by the process of saltation (Montague and Luker, 1994). The extent and character of this pollution depends on the chemical and physical characteristics of the riverbed and land-use in the catchment area (Klein 1962; Choe *et al*, 2002; Mulcahy, 1990). Construction sites are the most detrimental activity in terms of sediment runoff (Sonzogni *et al*, 1980), and street surfaces are important pollutant sources in all land types (Bannerman *et al*, 1993). Zinc was the most dominant heavy metal found in the Coventry results and can arise from a number of sources, as shown in Tables 2.4 and 2.5. Airborne sources include burning fossil fuels and smelting. As discussed in section 2.2.2 the creation of smokeless fuel

areas in the city have significantly reduced the incidence of using fossil fuels in the home, and there are no identified smelting plants in the centre of Coventry.

Volatile metals, especially those that form oxides (such as Cd, Pb and Zn) with boiling points at or below 1500°C, are vaporised during high temperature combustion processes such as incineration (Kaakinen *et al.*, 1975). They then condense onto the surfaces of ambient particles (Farmer and Linton, 1984), which may be transported with other suspended solids after deposition (Figure 2.2), becoming readily bioavailable under certain environmental conditions (low pH, as in acid rainfall) or dissolving in surface runoff (Farmer and Linton, 1984). The incidence of Zn emissions from the waste incinerator plant located within the city is not reported (www. environment-agency.gov.uk), although Pb is prevalent to levels of 100Kg annum^{-1}, and significant levels of Cu and Cr were recorded in data for the period to 2000. Dry atmospheric fallout can be responsible for large proportions of street dusts (section 2.2.3) (Montague and Luker, 1994, Bellinger *et al.*, 1982;Hedley and Lockley 1975). Other likely sources for Zn include wearing of vehicle tyres, corrosion of vehicles, paints and electronic goods as discussed in Chapter 2, and discharges from industrial process. There are 2 metal finishing plants located adjacent to the River Sherbourne within the city centre which could cause heavy metals contamination of localised soils, although surface water from both sites had previously been directed to the foul sewer as a result. These plants will also produce trade effluents discharging to the foul sewer, which contain controlled quantities of Cu, Cr, Ni and Cd. Any storm, illegal or emergency overflow from receiving foul sewers (as was the case in Gulson Road, Section 5.1), will therefore constitute a potential source of these metals. Metals can exist in many forms; they can be attached to inert sediments, be contained in immiscible fluids, occurring as particles, soluble salts or insoluble compounds, and in organic, inorganic or complex forms,

dependent on the prevailing redox and pH conditions (Montague and Luker, 1994). It is likely that Zn sources in the River Sherbourne arise from corrosion of roofing (Bannerman *et al.*, 1993), buildings, and the use of vehicles (Ellis *et al.* 1982; Zobrist *et al.*, 2000; Charlesworth & Lees, 1997; Fergusson, 1990), within the curtilage of the inner ring road, areas draining to the surface water drainage systems studied in Phase 1. Dust and dirt from traffic will include direct exhaust emissions of particulates (mainly from diesels) and dust resuspended from the road by passing traffic. The resuspended material will include local soil material, products of vehicle wear (rust, tyre rubber etc) and de-icing salt in the winter months, and consist of coarse particles that settle quickly leaving fine particles suspended in the air (Namdeo *et al.*, 1999). The contribution of metal corrosion to the Zn and Cd load in street dust is of great significance (De Miguel *et al.*, 1997). As a result of these sources, urban pavement drainage often contains significant quantities of anthropogenic metal elements, including Cd, Cu, Pb and Zn. Although Cu seems to accumulate from more than one source, (for example from roof drains, as discussed in section 2.2.4), the high concentrations of Cu collected near to busy roads, and the high correlation found between Pb and Cu in the street dust of Madrid suggests that corrosion has a special significance for its dispersal (De Miguel *et al.*, 1997).

Insoluble and adsorbed materials (section 2.2.3i) may collect until there is a storm of sufficient intensity to remove them (Harrison and Wilson, 1985). Morrison *et al.*, (1988) showed that developing anoxic conditions in gully pot traps could alter the Eh/pH environment enough to release bonded particulate metals into solution. Variability in runoff concentrations may, in part, be due to nature of different road surfaces, hydrological conditions, (for example, total volume and intensity of stormwater) (Lee *et al.*, 2004) and street cleaning efficiency (Sartor *et al.*, 1974; Ellis, 1979).

In previous studies, very little metal found in Coventry street dusts was in the residual form or exchangeable fraction, which means that following a change in environmental conditions e.g. pH, there is a potential for metals, in particular Cd, to be released (Charlesworth *et al.*, 2003). Any metals released in this way would then be flushed through the drainage network into streams and other watercourses (Figure 2.2).

Foster *et al.*, (1996) and Proffitt (1993) have shown that storm events can change prevailing environmental conditions by buffering the effects of acid rain on the one hand, and by flushing through the urban system on the other. The result is the remobilisation of metals and the 'first-flush' effect of a storm after a dry spell (see section 2.2.1). This effect was identified in the results for the November 2003 rainfall event (Figures 7.4.1 and 7.4.2). Short duration, high intensity summer storms are most likely to mobilise pollutants that have accumulated during the antecedent dry period (Montague and Luker, 1994).

8.2.4 Bacteriological contamination

As stated in Section 2.2.1 excrement and urine deposited on roads and pavements can be a significant source of bacteria, viruses, and soluble and particulate organic contaminants (Muschack, 1990) with high oxygen demands (Section 2.3.1). Dead animals will also contribute to the organic and bacterial contaminants discharged into the drainage systems. Where there are sewerage systems discharging to a watercourse through combined sewer overflows and misconnected foul sewers, Coliform bacteria (of faecal origin, arising from the gastrointestinal tract of people and animals) will be present. The bacterial content of separate stormwater is predominantly from non-human (domestic and wild animal) sources (Field *et al.*, 1993). Dufour (1984) identified that bacteria from sources other than the gastrointestinal tract of man and other warm-blooded animals (and are not therefore classed as faecal Coliforms), are also present in

freshwater, in high densities. These will include pathogens arising from agricultural sources. The River Sherbourne is not designated as bathing water under the 1976 EC Bathing Water Directive (76/160/EEC), and as such is not monitored by the Environment Agency for bacteria and pathogens (and no such determination was made in this research). However, the bacterial contamination of the River Sherbourne is likely to be significant, and should be considered if the amenity value (i.e. public accessibility to the watercourse) or proposed future use of the river is changed, as discussed in Section 8.1.3.

8.2.5 A simple model for the impacts of urban runoff in the River Sherbourne

A summary of all the trends identified, upstream and downstream of the city in monitoring the River Sherbourne is given in Table 8.2. As detailed in the results for each featured investigation (Section 7.2), concentration peaks for most parameters were identified before river levels increased sufficiently to reflect measured rainfall events, demonstrating a first flush effect (Choe *et al,* 2002), arising from local impervious surfaces and drainage systems. The Correlation between river level and some parameters was not significant as a result in the post-remedial featured investigations, although some trends identified in the pre-remedial stage more consistently (such as a fall in pH during rainfall events, and increases in BOD, SS and heavy metals with increases in rainfall, particularly in the earliest featured storm in March 2001), were repeated. This feature was demonstrated by the highly significant results recorded for increases in BOD, SS and Pb when the rainfall readings were adjusted to allow for time of travel, by up to 2 hours sequentially (Tables 7.12 – 7.14). The significant results for increases in heavy metals against rainfall and flow identified during March 2001 were not as apparent in the later measurements.

Table 8.2: Summary of general trends for featured investigations 2001 & 2003

Event & location		depth	BOD	TON	SS	Total P	pH	Cd	Cr	Cu	Zn	Pb	Cl	Temp.	DO % satn	NH_4^+N	Cont. pH	TDS	flow	rainfall
March 2001	US	■	■	■	■	■	■	■	■	■	■	■	■	■	↑	↓	↓	↓	↑	↑
	DS	↑	↑	↓	↑	↑	↓	↑	↑	↑	↑	↑	↑	↓	↑	↓	↓	↑	↑	↑
Trends		↑	↑	↓	↑	↑	↓	↑	↑	↑	↑	↑	↑	↓	↑	↓	↓	■	-	-
Dryweather 2003	US	↓	↓	■	■	-	■	-	■	↓	■	■	-	-	↓	■	↓	-	↓	-
	DS	↓	■	■	■	-	■	-	■	■	↑	■	-	-	↑	↓	↑	-	↓	-
Trends		↓		■	■	-	■	-	■	■	■	■	-	-	■	■	■	-	↓	-
November rainfall event 2003	Rain -1hr	↑	■	■	↑	-	■	-	-	■	■	■	-	-	↑	■	■	-	↑	■
	Rain -2hr	↑	■	■	↑	-	■	-	-	■	■	↑	-	-	↑	■	↓	-	↑	■
	level	-	↑	↓	↑	-	↓	-	-	■	■	↑	-	-	↑	↑	↓	-	↑	↑
	→ DS result	level	BOD	TON	SS	-	pH	-	-	Cu	Zn	Pb	-	-	DO % satn	NH_4^+N	Cont. pH	-	flow	rainfall
	Rain -1hr	↑	↑	↓	↑	-	■	-	-	■	■	■	-	-	-	-	-	-	-	■
	Rain -2hr	↑	↑	↓	↑	-	■	-	-	■	■	■	-	-	-	-	-	-	-	■
	level	-	↑	↓	↑	-	↓	-	-	■	■	↑	-	-	-	-	-	-	-	↑
General Trends		trend	↑	↓	↑	-	↓	-	-	■	■	↑	-	-	↑	↑	↓	-	↑	↑
US Concentration	Dry	-	12.5	-	4.69	1	8.1	0	1	2.56	10.3	1.19	-	-	96.5	0.36	-	-	-	-
	Rain	-	9.03	-	55.43	ND	7.9	0.15	1.75	10.7	51.2	10.7	-	-	108.13	0.08	-	-	-	-
DS Concentration	Dry	-	3.7	-	4.31	1	7.61	0	1.38	2.73	12.4	1.34	-	-	77.3	0.36	-	-	-	-
	Rain	-	16.9	-	103.07	ND	7.9	0.25	4.16	25.0	122.9	24.6	-	-	-----	-----	-	-	-	-
Trends with rainfall		US DS	↓ ↑	-	↑	↕	↓ ↑	↑	↑	↑	↑	↑	-	-	↑	↓	-	-	-	-

Key: ↑ increase ↓ decrease ↓↑ decrease upstream, increase downstream, ↔ no change ■ non detected ↑ significant results ↑ DS only

The improvement in water quality shown in Figure 3.4, and the reduction in pollutant concentrations towards the end of the research period summarised in Tables 7.6 and 7.16, demonstrated a reduced impact from urban runoff in the catchment. However, concentrations of pollutants remained generally higher downstream of the city, as indicated in the bottom section of Table 8.2, and a comparison of upstream and downstream sites (using data gathered in 2003 during dry weather and the rainfall event), in conjunction with the previous trends identified in all Phases (Sections 6.2 and 7.4), can lead to a simple model of what results could be currently expected during a monitoring run on the River Sherbourne.

During dry weather in the River Sherbourne;

1) Diurnal variation in pH, DO and temperature will be recorded. Total P levels in the watercourse, (arising from rural sources and numerous small sewage treatment plants upstream of the catchment) are very high (300-500$\mu g\ l^{-1}$), and the algal activity in the watercourse is pronounced, particularly at the upstream monitoring point, after the open section of watercourse. (Figure 4.16).
2) Ammonium levels will be reasonably constant, with average concentrations below detectable levels (0.5 $mg\ l^{-1}$) for sampled data, and around 300- 400$\mu g\ l^{-1}$ when using continuous monitors.
3) DO will remain high with levels reaching above 100% saturation during daylight hours, and falling to no less than 60% saturation during the hours of darkness.
4) Heavy metal concentrations will remain constant and within water quality guidelines (section 2.4), with Zn, Pb, Cu and possibly Cr detected, and Ni and Cd below analytical detection levels of 5$\mu g\ l^{-1}$ and 0.1$\mu g\ l^{-1}$ respectively.

During rainfall events of adequate intensity to mobilise street dusts and sediments (Lee and Bang, 2000);

1) BOD and SS will increase and Ammonium will decrease slightly, if no combined sewer overflows are operating, or if organic contaminants from local misconnections, leaf litter and other detritus have not accumulated in the local drainage systems.
2) The pH levels will fall upstream and downstream of the city, although the levels at Meadow Street will remain consistently higher and the impact on the upstream site will be greater. TON and TDS will also fall as a result of increased flows, although levels for SS will be higher downstream of the city as a result of urban runoff.
3) DO levels will remain higher than 50% saturation unless there is an influx of sewage or other organic contaminant as a result of the high level storm relief outlet at Hope Street (Figure 4.5) or the pumping station overflow at Park Road, (Figure 3.2), in which case it may fall to <10% saturation. Diurnal variation of dissolved oxygen will be disrupted in any case with gradual recovery dependant on the rainfall event.
4) Heavy metals will increase after the initial rainfall event with further smaller peaks, similar to those obtained for SS. Pollution concentrations for all parameters will be greater at the Humber Avenue site, by a factor or 2-4. All metals will be within water quality guidelines, although total Cu may give cause for concern and determination for the dissolved element is advised.
5) Specific conductivity concentrations may peak initially with the first rainfall but will fall by dilution, as river levels increase.

6) Water quality objectives will not be affected by short summer storms, but intermittent toxicological standards may be breached for DO% saturation in the River Sherbourne and possibly the River Sowe, although the river Avon is likely to remain compliant.

8.3 Testing the Hypotheses

The aims and objectives of this study into urban runoff problems, with particular emphasis on urban drainage in the City of Coventry, arise from the following initial Hypotheses:

i) Hypothesis A

That occasional spot sampling of the urban watercourses does not give an accurate assessment of the chemical water quality and that the use of biological sampling does not address the issue of identifying intermittent discharges in an inner City environment with culverted watercourses and streams. Furthermore that the use of continuous monitors can give an accurate graphical representation of the changeable nature of quality and flows in urban watercourses and assist in the investigation and removal of polluting intermittent organic discharges in a cost effective manner.

This hypothesis was tested by considering routine water quality data and comparing the results (Table 3.1) against data collected from continuous monitoring over long periods and intensive sampling over 12 to 14 hours, during dry weather, and rainfall events (Sections 5.1, 6.1. 7.1 and 7.2) during Phases 1, 2 and 3. The results were proven as discussed above for objectives 1, 2 and 4. Continuous monitors, used alone, or in conjunction with intensive automated composite sampling equipment, were identified as a cost-efficient method of identifying the changeable nature of water quality in an urban drainage system during rainfall, and an effective means of identifying intermittent

organic discharges in extensive drainage systems. Occasional spot sampling does not give a representative assessment of urban runoff. Biological sampling (Section 3.3) will identify the impact of persistent intermittent pollutions, but morphological changes to urban watercourses, such as the introduction of concrete culverts, and 'flashy' storm drainage systems may also reduce biodiversity at a monitoring site (Section 2.3.1b). Unfortunately biological sampling is infrequent and undertaken at few urban sites, so will not identify specific point sources of pollution.

ii) Hypothesis B

That analysis of phosphate concentration will reveal that combined sewer overflow (point) sources in an urban area, contribute to the high level of phosphate per capita discharged to receiving watercourses.

Early monitoring techniques did not include σ-P, and samples did not identify detectable levels (0.5 mg l^{-1}), of total P related to rainfall events. Comparisons against recorded post-remedial concentrations for total P averaging approximately 300 μg l^{-1} could not therefore be made. The featured rainfall event on March 2001 showed an increase in total P concentration, related to rainfall, rising to 450 μg l^{-1}. These results identify that using the nutrient classification system allied to the General Quality Assessment classification, the watercourse would be classed as Grade 5 with nutrient (P) levels described as 'Very High'. Orthophosphate levels remained below the detectable limit of 0.5 mg l^{-1} in sampled results (not detectable with the sondes used during continuous monitoring). Most of the watercourses in the River Avon catchment are considered to be eutrophic, with nutrient sources arising from rural agricultural areas and small sewage treatment works. Major sewage works in the area are subject to P removal before discharging to watercourses under the Urban Wastewater Treatment Directive (91/271/EEC). Nationally, 53% of rivers had high concentrations of phosphate (greater

than 0.1mg/l) in 2003, compared with 64% in 1990, as a result of P removal in sewage effluents and agricultural initiatives (Environment Agency WQ report, 2003). Removal of the combined sewers did not result in a decrease in total P to acceptable levels. As early results were not identified for total P analysis, it is not possible to determine whether levels had previously been higher in the watercourse during rainfall events. The hypothesis is therefore not proven nor disproved.

iii) Hypothesis C

That analysis of water quality during storm events at multiple sites on a continuous basis will reveal hitherto unknown cross connections between surface and foul sewers, broken sewers and industrial and commercial effluents quickly, and that removal of these illegal discharges will result in a marked improvement in water quality, as identified by routine sampling programmes, for affected watercourses.

The investigations carried out during Phase 1 in culverted watercourses draining to the River Sowe and River Sherbourne, were very successful in identifying sources of intermittent pollution, misconnections, cross connections and trade effluents, as discussed in Section 5.2. Many of the intermittent pollutions identified were initially masked by continuous discharges from misconnected foul sewerage systems and illegal cross connections between the foul and surface water sewers, and a number of illegal trade effluent discharges were taking place during the night or early evenings and would not have been detected by spot sampling.

As discussed above, objective 3 was to identify any impact of removing intermittent discharges from the surface water systems, and objective 5 was to identify any pollutants remaining, for consideration against future river uses, and water quality compliance. Monitoring the River Sherbourne, before and after the unsatisfactory storm overflows and intermittent pollution sources were addressed, identified significant

improvements in the quality of the watercourse receiving urban runoff during rainfall events, as discussed in Sections 3.9, 7.3,7.4 and 8.1, and demonstrated in Tables 3.1, 3.2, 7.6, 7.8 and 7.16; and figures 3.4-3.6 and 3.10-3.11. Objectives 1, 3 and 5 were fulfilled as a result of investigating urban watercourses (and surface water drainage systems) during Phases 1,2 and 3, and hypothesis C was therefore correct.

8.4 Conclusions, Future monitoring, and suggested future research

8.4.1 Conclusions

A number of major sources for organic contaminants have been identified in the River Sowe catchment, for removal during the course of this research, and heavy metals appear to be the main pollutants remaining in Coventry's urban watercourses. These contaminants are found in higher concentration downstream of the city centre culvert, although the levels identified are within current water quality guidelines. Most parameters analysed displayed a first flush phenomenon with pollutants that probably arise from sediments and street dusts deposited in surface water systems, and on local impervious areas such as roofs, roads and pavements, respectively. Further controls on vehicle emissions, and planned transport movement restrictions within the city (Coventry C.C. Urban Design Study Final Report 571,1999), accompanied by continuing improvements in emission control at the incinerator plant and other local industrial processes, will help to reduce the pollution sources further.

8.4.2 Future monitoring

Regular monitoring of local watercourses, both open and culverted, using intensive sampling and continuous monitors is essential to prevent deterioration of the improved situation with respect to water quality, and to identify and prioritise problems areas for investigation with limited resources. Failure to maintain this intensive monitoring capability, may lead to a return to poor quality watercourses, affected by unknown

intermittent pollution sources. As discussed in Sections 2.6 and 3.11, the Water Framework Directive (2000/60/EC) establishes an integrated approach to the protection, improvement and sustainable use of Europe's rivers, lakes, estuaries, coastal waters and groundwater (UKTAG 2006, www.wfduk.org). It requires that all inland and coastal waters within defined river basin districts must reach *good status* by 2015, and defines the environmental objectives and ecological targets to achieve this (Foundation for Water Research, 2005). The definition of good status is currently being determined by the member states.

The Environment Agency is the competent body for implementation of the Directive in England and Wales with SEPA identified for implementation in Scotland (Environment Agency, 2006), and will:

- Assess the present water quality in the river basin district
- Undertake analysis of the significant water quality management issues, including abstraction pressures
- Identify a programme of measures (PoM) for each river basin district
- Consult with key stakeholders and other interested parties about the characterisation, proposed PoM, and cost –benefit analysis.
- Implement the agreed PoM, monitor improvements in environmental quality, review progress and revise water management plans.

It is not yet clear how the monitoring programme will encompass an holistic approach to ecological status, or whether additional resources will be available to the competent body to carry out this work. The classification system, based on a worse case scenario (i.e. the lowest quality indicator will identify the water body as non-compliant, even if other factors are satisfactory) is nearing completion, and is currently being ratified at European level, along with the quantification of 'good ecological status'.

The Public have been constantly informed that water quality in rivers, bathing waters and water supply has improved over the years, and that increased Water Industry spending (and subsequently water bills) has been necessary to remove historical pollution problems for good. The message has been that this spending under the Asset Management Planning process has been a success and that we are now benefiting as a result. The requirements to improve ecological status under the Water Framework Directive may therefore be a harder message to give, and the extra funding required may not be acceptable, nor considered essential to the general public.

Meanwhile, a greater awareness of pollution prevention measures in industry (through widespread acceptance of Environmental Management Systems and improved chemical storage and disposal facilities), and environmental awareness in the community with a better understanding and appreciation of their local environment, is an appropriate way forward.

8.4.3 Suggested further research

Had sufficient resources been available, it would have been preferable to monitor all main outfalls to the culverted river section during each run, in conjunction with the two sites monitored in this research. Monitoring of the Albany Road outfall, in open watercourse (Figure 4.15) was not practical because of the risk of vandalism at the site. This was subsequently proven during the pre-remedial research (Phase 1), with the theft of one continuous monitor and significant damage to another. Studies undertaking monitoring of urban runoff discharges to the watercourse would complement the research carried out by Coventry University in monitoring river sediments and analysis of street dusts (Charlesworth *et al.*, 2003; Foster *et al.*, 1996; Charlesworth and Lees, 1999, 2001). The presence of heavy metals in Coventry's urban watercourses was not previously monitored for, and further research should identify soluble and total heavy

metal concentrations in discharges to the river to confirm whether the sources are from deposition onto local impervious areas, or arising from illegal discharge of trade effluents, contaminated land runoff or sedimentary deposits in the extensive drainage system investigated in Phase 1.

Bacterial contamination is not monitored in the River Sherbourne by the Environment Agency, as discussed in Section 8.2.4, and proposals (Coventry C.C. Urban Design Study Final Report 571, 1999) to open culverted sections of the river within the city centre (Section 8.1.3), should be accompanied by research into the potential risk to the public of infection from Coliform bacteria and other pathogens. Identification of sources (illegal overflows, sewer collapse and cross connections) by using the methodology outlined in Chapter 4 of this research can assist in reducing this potential risk.

Further consideration of nutrient sources in the River Sherbourne, during wet and dry weather conditions would also be beneficial; before the requirement for nutrient removal under the Urban Wastewater Treatment Directive (91/271/EEC) is applied to smaller sewage treatment plants in the vicinity, and before the programme of measures for 'at risk' watercourses, as required by the Water Framework Directive (2000/60/ EC), reaches a local level of implementation.

References

Abel, P.D. (1996) *Water Pollution Biology*. 2nd ed. London: Taylor& Francis.

Abu-Zeid, M., Shady, A.M., and Coulomb R. The World Council in Three years 1994-1997.(1998). *Water International* 23, 97-106.

Ahyerre, M., Chebbo, G., Tassin, B., and Gaume, E. (1998) Storm water quality modelling, an ambitious objective? *Wat.Sci.Tech.* 37(1), 205-213.

Alabaster, J.S., and Lloyd, R. (Eds). (1980) Water Quality Criteria For Freshwater Fish. London: Butterworths.

Alloway, B.J., and Ayres, D.C. (1997) 2nd ed. Chemical Properties of Environmental Pollution. London: Chapman & Hall.

Apte, S.C., and Gardner, M.J. (1991) Summary of trace metal speciation in natural waters. National Rivers Authority, report NR 2668.

Arntson, A.D., and Tornes, L.H. (1985) Rainfall runoff relationships and water quality assessment of Coon Creek watershed, Anoka County, Minnesota. *US Geological Survey of Water Resources.* Investigation Report 84-4013.

Ayers, M.A., Brown, R.G., Oberts, G.L. (1985) Runoff and chemical loading in small watersheds in the TCMA, Minnesota, *US Geological Survey of Water resources* Investigation Report 85-4122.

Bannerman, R.T., Owens, D.W., Dodds, R.B., Hornewer, N.J., (1993) Sources of pollutants in Wisconsin stormwater. *Water Sci Tecnol.*; 28(3-5): 241-59.

Bang, K.W., Lee, J.H., and Yu, M.J. (1997) A study of runoff characteristics of non-point sources in small urban watersheds. *J. Korea Soc. Water Quality* 13(1), 79-100.

Bartlett, R.E. (1976) *Surface Water Sewerage*. London: Applied Science Publishers.

Bartlett, R. E. (1981) *Surface Water sewerage*. 2nd ed. Essex: Applied Science Publishers Ltd.

Bartlett, Ronald E. (Ed). (1979) *Developments in sewerage*. Part 1. London: Applied Science Publishers Limited.

Bellinger, E.G. *et al.* (1982). The character and disposal of motorway runoff water. *Water Pollution Control.* 8(3), 372-389.

Benes, P., Cejhanova, M., and Havlic, B. (1985) Migration and Speciation of Lead in a River System Heavily Polluted from a Smelter. *Water Res.* 19, 1-6.

Boller, M., and Häfliger, M. (1996) Fate of heavy metals in various stormwater discharge system *Gas-Wasser-Abwasser* **76**(1), 3-15. (Translation H. Tilley). 2003.

Borchardt, D., and Sperling, F. (1997) Urban stormwater discharges: Ecological Effects on Receiving Waters and Consequences for Technical Measures, *Wat.Sci.Tech.*, 36(8-9), 173-178.

Boulding, K.E., Stahr, E.J., Fabricant S., and Gainsbrugh, M.R. (1971) *Economics of Pollution*. New York: New York University Press.

Bourg, A.C.M., and Bertin, C., (1996) Diurnal Variations in the Water Chemistry of a River Contaminated by Heavy Metals: Natural Biological Cycling and Anthropic influence, *Water, Air, & Soil Pollution (Historical Archive)*, 86(1-4), 101-116.

Brezonik, P.L., and Stadelmann, T.H., (2002) Analysis and Predictive Models of Stormwater Runoff Volumes, Loads, and Pollutants Concentrations from Watersheds in the Twin cities Metropolitan area, Minnesota, USA. *Water Res.* 36, 1743-1757.

Brown, H.S., Kasperton, R.E., & Raymond, S. (1990) 'Trace Pollutants'. In Turner, B.L., Clarke, W.C., Kates, R.W., Richards, J.F., Mathews, J.T., and Meyer, W.B. *The Earth as Transformed by Human Action* (pp. 437- 455). Cambridge: Cambridge University Press with Clark University.

Butler, D., and Clark, P., (1995) *Sediment Management in urban drainage catchments.*, Storey's Gate, London. CIRIA 134.

Characklis, G.W., and Weisner, M.R. (1997) Metals, and Water Quality in Runoff from Large Urban Watershed. *J. of Environ. Eng. Div.* ASCE, 123(8), 753-759.

Charlesworth, S.M., Everett, M., McCarthy, R., Ordóñez, A., and de Miguel E. (2003) A Comparative Study of Heavy Metal Concentration and Distribution in Deposited Street Dusts in a Large and a Small Urban Area: Birmingham and Coventry, West Midlands, UK. *Environment International*,29, 563-573.

Charlesworth, S.M., and Foster, I.D.L. (1993) The Effect of Urbanization on Sedimentation: The History of Two Lakes in Coventry, UK. In J. McManus, & R.W. Duck, *Geomorphology and sedimentology of lakes and reservoirs* (pp. 15 – 29). Chichester: Wiley.

Charlesworth, S.M., and Lees, J.A. (1997) The Use of Mineral Magnetic Measurements in Polluted Urban lakes and Deposited Street Dusts, Coventry, UK. *The Physics and Chemistry of the Earth*, 22(1-2), 203-206.

Charlesworth, S.M., and Lees, J.A. (1999) The Distribution of Heavy Metals in Deposited Urban Dusts and Sediments, Coventry, England. *Environmental Geochemistry and Health* 21, 1999.

Choe, J.S., Bang, K.W., and Lee, J.H. (2002) Characterization of surface runoff in urban areas. *Wat. Sci Techn.* 45(9), pp249-254

Clarke, A.G., Wilson, M.J., and Zeki, E.M. (1984). A Comparison of Urban and Rural Aerosol Composition Using Dichotomous Samplers. *Atmospheric Environment,*18, 1767-1775.

Clifforde, I.T., and Williams, W. D. (1997) *River Sowe/ Finham STW UPM Study – Final Report.* WRc Report No. UC 2973.WRc Swindon..

Collins, P.G., and Ridgeway, J.W. (1980) Urban Storm Runoff Quality in South-East Michigan. *Journal of the Environmental Engineering Division*, ASCE, 106(EE1), 153-162.

Colwill, D.M. (1985). *Water Quality of Motorway Runoff.* Transport & Road Research Laboratory. Report No. 823, Berkshire.

Council of the European Communities. (1991) *Directive Concerning Urban Wastewater Treatment.* (91/271/EEC). Official Journal L135.

Coventry City Council. (1999) *Urban Development in Coventry:* Coventry City Council Urban Design Study Final Report 571,

Crabtree, R., Dempsey, P., and Gent, R. (1995) *The UPM Demonstration Project*: Final Report. Foundation for Water Research, Wallingford. FR 0485.

Crompton T.R.. *Toxicants In The Aqueous Ecosystem*. John Wiley & Sons. 1997.

Dauber, L., Novak, B., Zobrist, J., and Zürcher, F. (1979) Pollutants in Stormwater from a Highway. *Stuttgarter Berichte zur Siedlungswasserwirtschaft* 64, 41-57.
Translation H.Tilley.

Deletic, A. (1998) The First Flush Load of Urban Surface Runoff. *Wat.Res*, 32(8), 2462-2470.

De Miguel, E., Llamas, J.F., Chacón, E., Berg, T., Larssen, S., Røyset, O., and Vadset, M. (1997) Origin and patterns of distribution of trace elements in street dust: unleaded petrol and urban lead. *Atmospheric Environment,*31(17), 2733-2740.

Dempsey, P., Eadon, A., and Morris, G. (1997) Simpol: A Simplified Urban Pollution Modelling Tool. *Wat.Sci.Tech.* 36(8-9) 83-88.

Demuynk, M., Rahn, K.A., Janssens, M., and Darns, R. (1976) Chemical Analysis of Airborne Particulate Matter During a Period of Unusually High Pollution. *Atmospheric Environment*, 10, 21-26.

DETR. 1997. The Urban Waste Water Treatment (England and Wales) Regulations 1994.

DETR (1997). *The Urban Wastewater Treatment (England and Wales) Regulations 1994. Working document for Dischargers and Legislators.* A Guidance Note issued by the Department of Environment, Transport and Regions and the Welsh Office.
DHV Burrow-Crocker Consultants. (1994) Earlsdon, Coventry Drainage Area Study (DAS). L-921-05. Reigate, Surrey.

Dierkes, C., and W.F. Geiger. (1999) Pollution Retention Capabilities of Roadside Soils. *Water Science and Technology* 39 201-208.

Douglas, I. (1985) Urban Sedimentology. *Progress in Physical Geography* 9(2): 255–280.

Drew, H.M. (1975) Metal-based Lubricant Compositions, Noyes Data Corporation, N.J.

Drewett J., and Roberts J. *Midland Rivers*. Quercus. 1996.

Driver, N. E., and Tasker, G. D. (1990) Techniques for Estimation of Storm-runoff Loads, Volumes, and Selected Constituent Concentrations in Urban Watersheds in the United States. *US Geological Survey of Water-Supply* Paper 2363.

Droppo, I.G., Irvine, K.N., Murphy, T.P. and Jaskot, C. (1998) Fractionated Metals in Street Dust of a Mixed Land Use Sewershed, Hamilton, Ontario. *Hydrology in a Changing Environment III. British Hydrological Society*; 383-394

Duffus, J.H., Heavy Metals- A Meaningless Term? (2002) (IUPAC technical report) *Pure Appl. Chem.*, 74(5)793–807.

Dufour, A.P.(1994) Health Effects Criteria for Fresh Recreational waters. *US.EPA report No. EPA-600/1-84-004.*

Dugan, P.R. (1974) Biochemical Ecology of Water Pollution. 3rd Edition. New York: Plenum Press.

Ehrlich, P.R., and Ehrlich, A.H. (1972) Population, Resources, Environment. Issues in Human Ecology. 2nd Edition, San Francisco: W.H. Freeman & Co.

Ellis, J.B. (1979) The nature and sources of urban sediments and their relation to water quality: A case study from N.W. London. In *Man's impact on the hydrological cycle in the UK.* (Ed. G. Halls) Gro Abstracts Ltd. (Cambridge)

Ellis, J.B. The Management and Control of Urban Runoff Quality (1989) *Journal of the Institute of Water and Environmental Management.* 3(4).

Ellis, J.B., and Revitt, D.M. (1982) Incidence of Heavy Metals in Street Surface Sediments: Solubility and Grain Size Studies. *Water, Air and Soil Pollution,* 17, 87–100.

Ellis, J. B. (1991) The Design and Operation of Vegetation Systems for Urban Runoff Quality Control. *Proc. of 3rd Standing Conf. on Stormwater Sci. Control,* Coventry Polytechnic.

Ellis, J. B., Revitt, D. M., Harrop, D. O., and Beckwith, P. R. (1987) The Contribution of Highway Surfaces to Urban Stormwater Sediments and Metal Loadings. *The Sci. of the Total Environment.* **59**, 339-349.

Ellis, K.V., White G., and Warn A.E. (1989) *Surface Water Pollution and Its Control.* Basingstoke: Macmillan Press.

Environment Agency. (1998) *Local Environment Agency Plan (LEAP) – Warwickshire Avon.* Tewkesbury.

Environment Agency. *Water Quality in the Midlands.* WQ Reports 1997- 2003. Solihull.

Environment Agency. (1998) *Aquatic Eutrophication in England and Wales. A Proposed Management Strategy.* Consultative Report. Environmental Issues Series. Bristol: Environment Agency.

Environment Agency (2005) *Water for life and Livelihoods – A Framework for River Basin Planning.* Bristol: Environment Agency.

European Council Directive 96/61/EC of 24 September 1996 concerning Integrated Pollution Prevention and Control **31996L0061** *Official Journal L* **257**, 0026 - 0040

Extence, C.A. (1978). The Effects of Motorway Construction on an Urban Stream. *Environmental Pollution.* 17, 245-252.

Farmer, A. (1997) *Managing Environmental Pollution.* London: Routledge.

Farmer, M.B., and Linton R.W. (1984) Correlative Surface Analysis Studies of Environmental Particles. *Environmental Science and Technology,*18, 319-326, UK.

Ferguson, B.K. (1998) *Introduction to Stormwater. Concept, Purpose, Design.* John Wiley & Sons, Inc.

Fergusson, J.E. (1990). *The Heavy Elements: Chemistry, Environmental Impact and Health Effects.* Oxford: Pergammon Press.

Field, R. (1985) Urban Runoff: Pollution Sources, Control and Treatment. *Wat.Res. Bull.*21(2). 197-206.

Field, R., Masters, H., and Singer, M. (1982) An Overview of Porous Pavement Research *Water Resources Bulletin.* 18(2) 265-270.

Field, R., Masters, H., and Singer, M. (1982) Status of Porous Pavement Research. *Water Research* 16(6) 849-858.

Field, R., O'Shea, M., and Brown, M.P. (1993) The Detection and Disinfection of Pathogens in Storm-generated Flows. *Wat. Sci. Tech.* 28(3-5) 311-315.

Forster, J. (1996) Patterns of Roof Runoff Contamination and Their Potential Implications on Practice and Regulation of Treatment and Local Infiltration. *Wat.Sci.Tech.* 33(6), 39-48.

Forstner, U. (1983) Assessment of heavy metal pollution in rivers and estuaries. In: Thornton, I (Ed.) *Applied Environmental Geochemistry.* London: Academic Press 395-423.

Foster, I.D.L.,Charlesworth, S.M., and Proffitt, S.B. (1996) Sediment-Associated Heavy Metal Distribution in Urban Fluvial and Limnic Systems; a Case Study of the River Sowe, UK, *Arch. Hydrobiol. Spec. Issues Advanc. Limnol.* 47, 537 – 545.

Foster, I.D.L., Sheasby, J., Wade, S., and Harrison, S. *Eutrophication in Controlled Waters in the Warwickshire Avon Catchment.*Coventry University, 1998.

Freeman, P. Water Resources Act, 1991. HMSO. 1991.

FWR. (1994) *Urban Pollution Management Manual.* FR/CL 0002. Foundation for Water Research, November 1994.

Godfrey, A. (1996) *Old Ordnance Survey Maps, Coventry 1905.* Jarrow: Peterson Printers.

FWR (1998) *Urban Pollution Management, Second Edition (UPM2),* Foundation for Water Research, G Morris, A Agg, C Chubb, I Clifford, K Ridout, P Singleton, J Tyson, A Wilson, October 1998 – FR/CL0009 –CD format.

Gromaire, M.C., Garnaud, S., Saad, M., and Chebbo, G. (2001) Contribution of Different Sources to the Pollution of Wet Weather Flows in Combined Sewers. *Wat.Res.*, 35(2),521-533.

Gromaire-Mertz, M.C., Garnaud, S., Gonzalez, A. and Chebbo, G. (1999) Characterisation of Urban Runoff Pollution in Paris. *Wat.Sci.Tech.*, 39(2), 1-8.

Grum, M., Aalderlink, R., Lijklema, L., and Spliid, H. (1997) The Underlying Structure of Systematic Variations in the Event Mean Concentrations of Pollutants in Urban Runoff. *Wat.Sci.Tech.*, , 36 (8-9), 135-140.

Gupta, K., and Saul, A.J. (1996) Specific Relationships for the First Flush Load in Combined Sewer Flows. *Wat. Res.*, 34(6), 1773-1780.

Hall, M.J. (1984) Urban Hydrology. Essex: Elsevier Applied Science Publishers.

Hall, M. J., and Ellis, J B. (1985) Water Quality Problems in Urban Areas. *Geo.Journal* 11(3), 265-275.

Hares, R.J., and Ward, N.I. (1999) Comparison of the Heavy Metal Content of Motorway Stormwater Following Discharge into Wet Biofiltration and Dry Retention Ponds along the London Orbital (M25) motorway. *The Science of the Total Environment,*235 169-178.

Harremoës, P. (1981) Urban Storm Drainage and Water Pollution.. *2nd International Conference on Urban Storm Drainage*. Urbana, Illinois USA.

Harrison, R.M. (1992) *Pollution, Causes, Effects & Control*. 2nd ed. The Royal Society Of Chemistry.

Harrison, R.M., and Wilson, S.J. (1985) The Chemical Composition of Highway Drainage. 1) Ions and trace metals. *The Science of the Total Environment*, 43, 89-102.

Harrison, R.M., and Wilson, S.J. (1985) The Chemical Composition of Highway Drainage. 2) Chemical Associations of Metals in the Suspended Sediment. *The Science of the Total Environment*, 43, 89-102.

Harrison, R.M., and Wilson, S.J. (1985) The Chemical Composition of Highway Drainage. 3) Roof Water Metal Speciation Characteristics. *The Science of the Total Environment*, 43, 89-102.

Harrison, R.M., Laxen D.P.H., and Wilson S.J. (1981) Chemical Associations of Lead, Cadmium, Copper and Zinc in Street Dusts and Roadside Soils. *Environmental Science and Technology*, 15(11), 1376-1383.

Haswell Consulting Engineers. (1999) *Albany Road CSO Diversion along Meadow Street. Coventry* (for Environment Agency. Tewkesbury)

Hedley, G., and Lockley, J.C. (1975) Quality of Water Discharged from an Urban Motorway. *Jour. Wat Poll. Control.*74, 659-674.

Herrmann, R., Daub, J., Förster, J., and Striebel, T. (1994) Chemodynamics of Trace Pollutants During Street Runoff. *Wat.Sci.Tech.* 29(9), 73-82.

Hewitt, C.N., and Rashed, M.B. (1992) Removal Rates of Selected Pollutants in the Run-off of Waters from a Major Rural Highway. *Water Res.* 12, 359-364.

HMSO. (1989) DoE Circular 7/89 (Circular 16/89 Welsh Office), *Water and the Environment.* Department of the Environment and Welsh Office.. 30th March 1989.

HMSO. (2000) *The Air Quality Strategy for England. Scotland, Wales and Northern Ireland – working together for clean air*. DETR. Cm 4548. January 2000.

HMSO. (1973) *Pollution Prevention and Control (England and Wales) Regulations 2000* SI 2000/1973

HMSO (1986) *Road Vehicles (Construction and Use) Regulations*. Department Of Transport.

Houba, C., Remacle, J., Dubois, D., and Torez, J. (1983) Factors Affecting the Concentrations of Cadmium, Zinc, Copper and Lead in the Sediments of the Vesdre River. *Water Res.* 17, 1281- 1286.

Hvitved-Jacobson, T., and Yousef, Y.A. (1991) Highway Runoff Quality, Environmental Impacts and Control. In *Highway Pollution*, eds. R.S.Hamilton and R.M. Harrison London: Elsevier : pp 165-208.

Hvitved-Jacobson, T. (1986). Fate of Phosphorus and Nitrogen in Ponds Receiving Highway Runoff. *The Science of the Total Environment.* 33, 259-270.

Hynes, H.B.N. *The Ecology of Running Waters*. University Press. . Liverpool. 1970.

Irvine, A.H., (Ed). (1954) *The Modern University Dictionary*. London: The Educational Book Co. Ltd.

Jackson A.R.W., and Jackson, J.M. (1996) *Environmental Science – The Natural Environment and Human Impact*. Essex: Longman Group.

Johansson, K., Bringmark, E., Lindevall, L., and Wilander, A. (1995) Effects of Acidification on the Concentrations of Heavy Metals in Running Waters in Sweden. *Water, Air, & Soil Pollution (Historical Archive)*, 85(2),779 – 784.

Kaakinen, J.W., Jorden, R.M., Lawasani, M.H., and West R.E. (1975) Trace Element Behaviour in a Coal Fired Power Plant. *Environmental Science and Technology*,9, 862-869, UK.

Kablitz, K., Wennrich, R. (1998) Mobilization of heavy metals and arsenic in polluted wetland soils and its dependence on dissolved organic matter. *The Science of the Total Environment*, 209(1), 27-39.

Klein, L. (1962) *River Pollution 2. Causes and effects*. 1st ed. Butterworth & Co.

Klein, L. (1972) *River Pollution 2. Causes and effects*. 5th edition. Butterworth & Co.

Klein R.D. (1979) Urbanization and Stream Quality Impairment. *Water Resources Bulletin*, American Water Resources Association. 15(4), 948-963.

Kolsky, P. (1998) *Storm drainage. An Engineering Guide to the Low Cost Evaluation of System Performance.* London: Intermediate Technology Publications Ltd.

Kowalczyk, G.S., Gordon, G.E., and Rheingraver, S.W. (1982) Identification of Atmospheric Particulate Sources in Washington DC, Using Chemical Element Balances. *Environ Sci Technol.* 16,79-90.

Krenkel, P.A. (1973) (Ed) *Heavy Metals In The Environment.* An International Conference, Nashville, Tennessee: Pergammon Press.

Laws, E.A. (1993) *Aquatic pollution: An introductory text.* (2nd ed). New York: John Wiley & Sons.

Laws, E.A. (2000) *Aquatic Pollution: An Introductory Text.* (3rd ed). New York: John Wiley & Sons..

Laxen, D.P.H., and Harrison, R.M. (1977) The Highway as a Source of Water Pollution: An Appraisal with the Heavy Metal Lead. *Wat. Res.* 11, 1-11.

Lee, H., Lau, S-L., Kayhanian, M., and Strenström. (2004) Seasonal First Flush Phenomenon of Urban Stormwater Discharges. *Wat. Res.* 38, 453-463.

Lee, J-H., and Bang, K-W. (2000) Characterisation of Urban Stormwater Runoff. *Wat.Res.*, 34(6), 1773-1780.

Lee, G. Fred., and Jones-Lee, Anne. (1993) Water Quality Impacts of Stormwater-Associated Contaminants: Focus on Real Problems. *Water Sci. and Tech.*, Vol. 28(3-5), 231-240.

Leecaster, M.K., Schiff, K., and Tiefenthaler, L.L. (2002) Assessment of efficient sampling designs for urban stormwater monitoring. *Water Res.* 36(6), 1556-64.

Lockwood, A.P.M. (Ed) (1976) *Effects of Pollutants On Aquatic Organisms*, Cambridge: Cambridge University Press.

Los Angeles County Department of Public Works. (2000). *Integrated Storm Water Assessment Report 1994-2000.*

Los Angeles County Department of Public Works. (1999). Los Angeles County 1998-99 *Stormwater Monitoring Report.* July 14, 1999.

Los Angeles County Department of Public Works (LACDPW). (2000*). Annual Hydrologic Report.* 1999-2000.

Luker, M., and Montague, K. (1994) *Control of Pollution from Highway Drainage Discharges.* Storey's Gate, London: CIRIA 142.

Lundberg, K, Carling, M, Lindmark, P. (1999) Treatment of Highway Runoff: a Study of Three Detention Ponds. *The Science of the Total Environment* 235: 363-365.

Mackie, A.M., and Davies, C.H. (1981) Environmental Effects of Traffic Changes. *TRRL Report LR1015*, Transport and Road Research Laboratory, Crowthorne, UK.

Macklin, M. (1992) Metal Pollution of Soils and Sediments. In M.D. Newson, *Managing the Human Impact on the Natural Environment: Patterns and Processes.* London: Bellhaven Press: pp. 172-195.

Mannion, A.M. (1997) *Global Environmental Change: A Natural and Cultural Environmental History.* (2nd edition.) Prentice Hall.

Mance, G. (1987) *Pollution Threat of Heavy Metals in Aquatic Environments.* London: Elsevier Applied Science.

Mason, C F. (1996) *Biology of Fresh Water Pollution*, 3rd ed. Longman Press.

Mason, C F. (2002) *Biology Of Freshwater Pollution.* 4th ed. Longman Press.

McNeill, A. and Olley, S. (1998) The effects of motorway runoff on watercourses in South-West Scotland. *J.CIWEM* 12, 433-439.

Mesuere, K., and Fish, W. (1989) Behaviour of runoff – derived metals in a detention pond system. *Water Air Soil Pollut.* 47: 125-138.

Ministry of Housing and Local Government. (1970) *Technical Committee on Storm Overflows and the Disposal of Storm Sewage - Final Report.* HMSO.

Moorcroft, S.M., and Laxen, D.P.H. (1990) Assessment of Dust Nuisance. *Environmental Health,* August, 215-217.

Morrison, G.M.P., Revitt, D.M, and Ellis J.B. (1990) Metal Speciation in Stormwater Systems. *Water Science Technology,* 22(10/11), 53-60.

Morrison, G.M.P., Revitt, D.M., Ellis J.B., Svensson G., and Balmer, P. (1988) Transport mechanisms and processes for metal species in a gullypot system. *Water Research.* **22**(11).

Mulcahy, JP. (1990) *Phosphorus Export in the Twin Cities Metropolitan Area.* Technical Report Metropolitan Council, St. Paul, MN.

Mungur, A.S., Shutes, R.B.E., Revitt D.M., and House, M.A. (1995) An Assessment of Metal Removal from Highway Runoff by a Natural Wetland. *Water Sci Technol* 3 169-175.

Murde, J.M., and Ney, J.J. (1986) Patterns of Accumulation of Heavy Metals in the Sediment of Roadside Streams. *Arch. Environ. Contam. Toxicol.* 15, 489-493.

Murrell, K (1998) *Case Study: River Quality Modelling for Urban Pollution Management using MIKE 11,* WRc WaPUG user note 36.

Murrell, K., Hyde, M.L., and Sedgwick, C. (1998) Water Quality Modelling for Urban Pollution Management of the River Sowe and Avon in the UK. *(unpublished).*

Muschack, W. (1990). Pollution of Street Runoff by Traffic and Local Conditions. *The Science of the Total Environment.* 93, 419-431.

Namdeo, A.K., Colls, J.J., and Baker, C.J. (1999) Dispersion and Re-suspension of Fine and Coarse Particulates in an Urban Street Canyon. *The Science of the Total Environment,* 235, 3-13.

National Rivers Authority. (1993) *Guidelines for AMP2/ Periodic Review. Effluent Quality (version 2).* Approved by the Quadripartite Meeting.

NRA (1991) *Draft Policy for determining consents for storm and emergency overflows*, CFD/AG001.

Nazari, M.M., Burston, M.W., Bishop, P. K., and Lerner, D. N. (1993) Urban Ground-Water Pollution: A Case Study from Coventry, United Kingdom *Groundwater* 31(3) 417-424.

Novotny, V., Olem, H. (1994) *Water Quality: Prevention, Identification and Management of Diffuse Pollution.* New York: Van Nostrand Reinhold.

NSCA (1999) *Pollution Handbook*. National Society for Clean Air and Environmental Protection.

Perdikaki, K., and Mason C.F. (1999) Impact of Road Runoff on Receiving Streams In Eastern England. *Wat. Res.*33 (7), 1627 – 1633.

Prest J. (1960) The industrial Revolution in Coventry. London: Oxford University Press.

Proffitt, S.B. (1993) Heavy Metal Partitioning in the River Sowe Catchment: a Study of the Extent, Sources and Processes of Heavy Metal Contamination. BSc. Dissertation, Coventry University.

Quality of Urban Air Group (1993). *Urban Air Quality in the United Kingdom* (First Report of the Urban Air review group). London: Department of the Environment.

Rand, G. M., Wells, P. G., and McCarty, L. S. (1995) 'Introduction to Aquatic Toxicology', In *Fundamentals of Aquatic Toxicology*, G. M. Rand (Ed.), Washington DC: Taylor & Francis.

Ravera O. (1978) (Ed) Biological Aspects of Freshwater Pollution. Commission for European Communities: Pergammon Press.

Review Group on Acid Rain. (1997) *Acid Deposition in the United Kingdom 1992-1994.* Fourth report of the Review Group on Acid Rain. Published by AEA Technology plc.

Robien, A., Striebel, T., and Herrmann, R. (1997) Modeling (sic.) of Dissolved and Particle–bound Pollutants in Urban Street Runoff. *Wat.Sci.Tech.* 36 (8-9), 77-82.

Saget,A., Chebbo, G., and Bertrand-Krajewski, J. (1995) The First Flush in Sewer Systems. In *Proc. Int. Conf. On Sewer Solids-Characteristics, Movements, Effects and Control,* Dundee, UK., pp. 58-65.

Sansalone, J., and Buchberger, G. (1997) Characterization of Solid and Metal Element Distributions in Urban Highway Stormwater. *Wat. Sci. Tech.* 36(8-9), 155-160.

Sansalone, J.J., and Buchberger, S.G. (1997) Partitioning and First Flush of Metals in Urban Roadway Storm Water. *J. Environ Eng.* ASCE 123 2, 134-143.

Sartor, J.D., Boyd, G.B., and Agardy, J. (1974) Water pollution aspects of street surface contaminants. *Journal WPCF.* 46(3), 458- 467.

Scottish Development Department (1977) *Working Party on Storm Sewage (Scotland), Storm Sewerage Separation and Disposal.* HMSO. Edinburgh.

Shutes, R.B.E., Revitt, D.M., Lagerberg, I.M., Barraud, V.C.E. (1999) The design of Vegetative Constructed Wetlands for the Treatment of Highway Runoff. *The Science of the Total Environment* 235 189-197.

Smith, F. *Coventry, Six Hundred Years of Municipal Life.* 2nd ed. Baynard Press, 1946.

Smol J.P. (2002) *Pollution of Lakes and Rivers.* Oxford University Press.

Society for General Microbiology. (1954) *4th Symposium, Autotrophic Organisms,* London: Cambridge University Press.

Sonzogni, W.C., Chesters, G., Coote, D.R., Jeffs, D.N., Konrad, J.C., Ostry, R.C., Robinson, J.B., (1980) Pollution from land runoff. *Environ. Sci. Technol.*14(2) 148-53.

Stenstrom, M.K., Lau, S-L., Lee, H-H., Ma, J-S., Ha, H., Kim, L-H., Khan, S. and Kayhanian, M. (2003) First Flush Stormwater runoff from Highways (year4). *Research report for Department of California Transportation*, July, 2003.

Strecker, E.W., Driscoll E.D., Shelley P.E., Gaboury D.R., Sartor, J.D. (1990) The U.S. Federal Highway Administrations Receiving Water Impact Methodology. *Sci. Tot. Environment* 93, 489-498.

Street, A., and Alexander W. (1994) Metals in the Service of Man. Middlesex, England: Penguin.

Taylor, E.W., (Ed)(1996) *Toxicology of Aquatic Pollution. Physical, Molecular and Cellular Approaches.* Society for Experimental Biology. Seminar Series 57.Cambridge University Press.

Tebbutt, T. (1977) *Principles of Water Quality Control.* 2nd edition. Oxford: Pergammon Press.

Tebbutt, T. (1998) *Principles of Water Quality Control.* 5th edition. Butterworth-Heinemann.

Tiefenthaler, L., Schiff, K., Bay, S., and Greenstein, D. (2002) *Effect of Antecedent Dry Periods on the Accumulation of Potential Pollutants on Parking Lot Surfaces using Simulated Rainfall.* Southern California Coastal Water Research Project Annual Report, 2001-2002.

Tiefenthaler, L., and Schiff, K. (2002) *Effects of Rainfall Intensity and Duration on First Flush of Stormwater Pollutants*. Southern California Coastal Water Research Project Annual Report, 2001-2002.

United States Environmental Protection Agency (EPA), (1983) *Results of the Nationwide Urban Runoff Program*. Volume 1 – Final Report. Washington, DC: U.S. EPA Water Planning Division. WH-554. December, 1983.

Urban Wastewater Treatment Directive (91/271/EEC) Official Journal L 135, 30/05/1991 P. 0040 – 0052, 1991.

Urbonas, B., and P. Stahre., (1993) *Stormwater Best Management Practices and Detention for Water Quality, Drainage, and CSO Management*. New Jersey: Prentice Hall.

US Environmental Protection Agency, 1983) *Results of the nationwide urban runoff program, vol.1. Final report*, Water Planning Division, US EPA, Washington DC. Wat.Res. 35(2), 521-533.

US EPA. (1986) *Quality criteria for water 1986*. Environmental Protection Agency, EPA 440/5-86-001.

US EPA (1990) *National Pollutant Discharge Elimination System Permit Application Regulations for stormwater discharges*. Final Rule. Federal Register, **55**(222), 47990-48091.

US EPA (1992). *Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliance*; Final Rule, 40CFR part 131, Federal Register, **57**(246), 60848-60923.

US DFWPCA. (1969) *Water Pollution Aspects of Urban Runoff*, US Dept. of the Int. Federal Water Poll. Control Administration. WP-20-15.

Van Hassel, J.H., Ney, J.J., and Garling, D.L., Jr. (1980) Heavy Metals in a Stream Ecosystem at Sites Near Highways. *Trans. Am. Fish. Soc* 109, 636-643.

Vorreiter, L., and Hickey, C. (1994) Incidence of the first flush phenomenon in catchments of the Sydney Region. In *National Conf. Publication – Institute of Engineers, Australia*, 3, (94/15), 359- 364.

Walker, C.H., Hopkin, S.P., Sibly, R.M., and Peakall, D.B. (1997) *Principles of Ecotoxicology*. 2nd Edition. London: Taylor & Francis Ltd.

Ward, B., and Dubos, R. (1974) *Only One Earth – The Care and Maintenance of a Small Planet*. Middlesex, England: Penguin Books.

Welch, E.B. (1992) *Ecological Effects of Wastewater*. 2nd ed. Chapman & Hall.

Whipple, W., and Hunter, J.V. (1981) Settleability of Urban runoff Pollution, *J. of the WPCF* 53(12) 1726-1731.

WRc. (1993). *Surface water outfalls, quality and environmental impact management.* Report No. VM1400, WRc, Swindon.

WRc. *Urban Pollution Management: Consenting Wet Weather Discharges*. NRA/ WRc UPM Training Team. Report No. UC 2692(A). Swindon. 1996.

Yousef, Y.A., Wanielista, M.P., Hvitved-Jacobsen, T., and Harper, H.H. (1984) Fate of Heavy Metals in Stormwater Runoff from Highway Bridges. *Sci Total Environ* 33 233-244.

Zhao, Y., Marriott, S., Roger, J., and Iwugo, K. (1999) A Preliminary Study of Heavy Metal Distribution on the Floodplain of the River Severn, UK by a Single Flood Event. *The Science of the Total Environment* 243/244 219-231.

Zinder, B., Schumann, T., and Waldvogel, A. (1988) Aerosol and Hydrometer Concentrations and their Chemical Composition During Winter Precipitation along a Mountain Slope–II. Enhancement of Below-Cloud Scavenging in a Stably Stratified Atmosphere. *Atmospheric Environment* 22(12) 2741-2750.

Zobrist, J., Müller, S.R., Ammann, A., Bucheli, T.D., Mottier V., Ochs, M., Schoenenberger, R., Eugster, J., and Boller, M. (2000) Quality of Roof Runoff for Groundwater Infiltration. *Wat.Res.* 34(5), 1455 – 1462.

Web sites:

a) Climate change

American decision on Kyoto: http://www.usembassy.it/pdf/other/RL30692.pdf

American position on global warming www.usembassy.it/pdf/other/RL30692.pdf

Friends of the Earth – climate change www.foe.uk

G8 summit Montreal, 2005 www.G8.gov.uk

Air Pollution and vehicle emissions

(vehicles emissions and numbers of vehicles in use – including 1981).

DEFRA and ARIC www.ace.mmu.ac.uk

National Society for Clean Air and Environmental Protection: http://www.nsca.org.uk

NSCA, 2006 nscaorguk.site.securepod.com

www.engineeringtalk.com

www.ace.mmu.ac.uk

www.cityoflondon.gov.uk

www.portfolio.mvm.ed.ac.uk

b) The Water Framework Directive

The Water Framework Directive – a summary. (Foundation for Water Research 2005 Information note FWR-WFD02 www.euwfd.com

UKTAG 2006, www.wfduk.org

www.defra.gov.uk

www.environment-agency.gov.uk

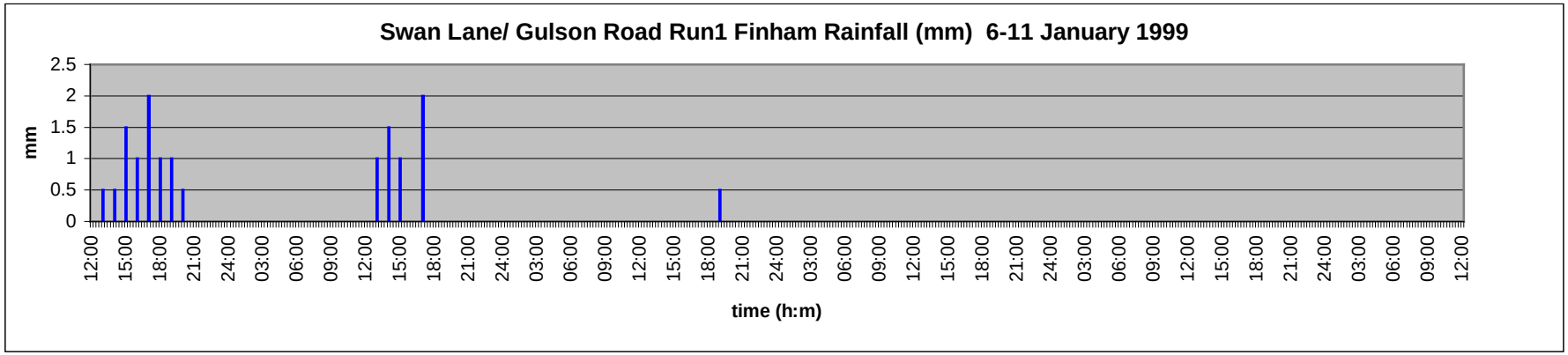
c) Urban runoff

www.ladpw.org/wmd/NPDES/report_directory.cfm first flush investigation LACDPW

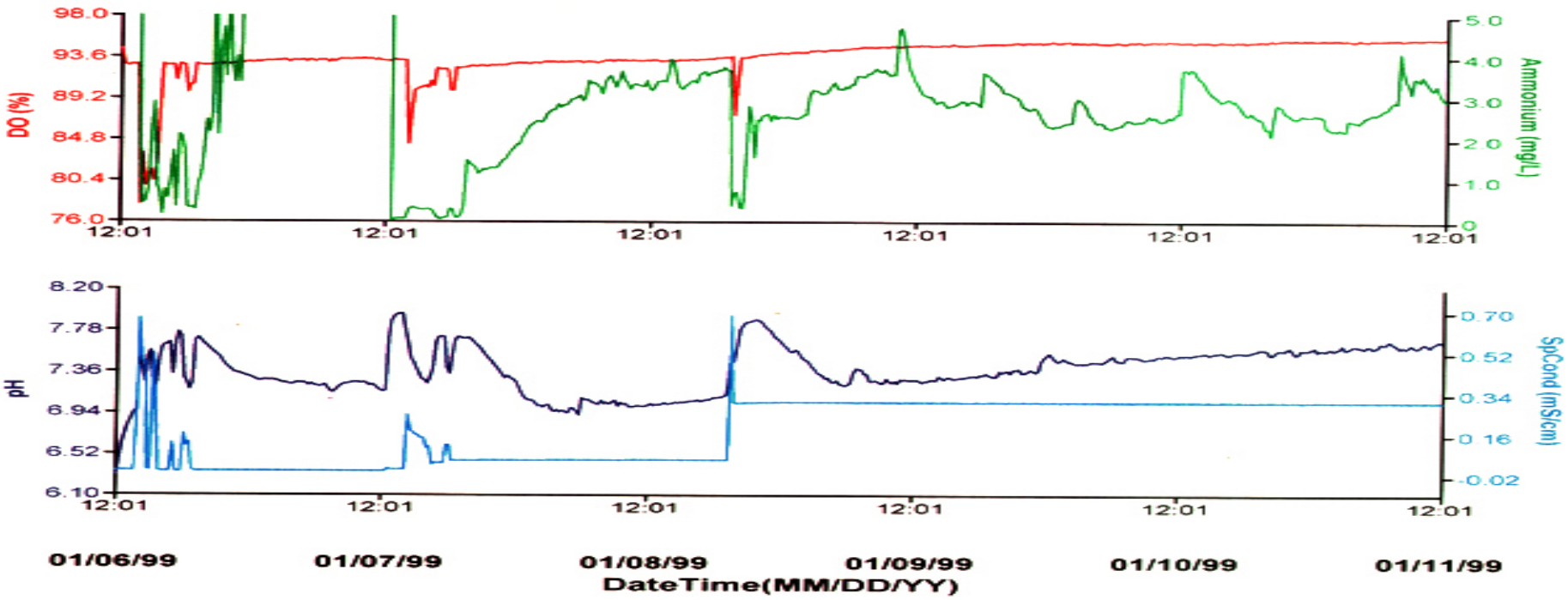
Legislation referred to in text:

- Nitrates Directive (91/676/EEC) - identification of Nitrate Vulnerable Zones to control nitrate pollution from diffuse sources
- Urban Wastewater Treatment Directive (91/271/EEC) – to control urban & certain Industrial wastewaters, including treatment standards and nutrient removal
- Discharge of Dangerous Substances Directive (76/464/EEC) – prevention (List I) and control (List II) of emissions at source of identifed substances
- Groundwater Directive (80/68/EC) – prevents and controls List I & II discharges to groundwater resources, including disposal of spent agrochemicals
- Water Framework Directive (2000/60/EC) Holistic approach to ecological quality assessment and improvement, based on river basin catchments
- The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003 – Implementation tool for Water Framework Directive
- Water Resources Act, 1991 (H.M.S.O., 1991). Water Quality legislation – controlled waters concerning quality and quantity of rivers and lakes
- Clean Water Act (US) 1977.Discharges from point sources require EPA permit.
- Integrated Pollution Prevention and Control Directive (IPPC 96/61/EC). Controls prescribed sites under one permit using integrated legislation
- Pollution Prevention and Control (England and Wales) Regulations 2000 (SI 2000/1973) -Tool for implementation of IPPC in England and Wales
- Road Vehicles (Construction and Use) Regulations 1986)
- EU emission standards (EC Directive 91/441/EEC). Vehicle emission standards and controls on new vehicles
- Environment Protection Act, 1990 New powers to control environmental issues in 4 Parts: IPC/Air; Controlled waste; Nuisance & clean air; Litter respectively
- Environment Act, 1995. Formation and duties of Environment Agency
- The Surface Waters (River Ecosystem) (Classification) Regulations 1994, (SI 1994 No. 1057) Prescribes classification of watercourses to allow for statutory quality objectives (WQOs)
- EC Freshwater Fish Directive (78/659/EEC) Sets limits and controls for cyprinid and salmonid fisheries
- Water Act 1989 (now Water Act 2003). Abstractions and Water Industry Regulation
- Clean Air Acts of 1956 and 1968 (www.cityoflondon.gov.uk).
- EC Bathing Water Directive (76/160/EEC). Determines water quality standards for bathing waters in Europe. (493 coastal waters, and 9 inland bathing waters in UK)

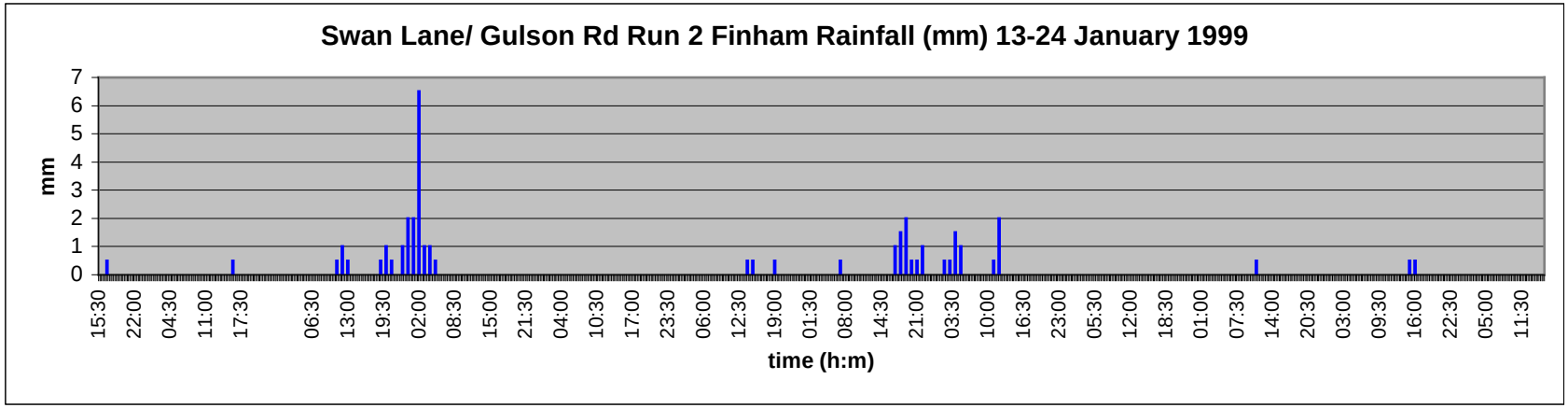
Swan Lane Culvert/ Gulson Road run 1. 6 – 11 January 1999
Finham Rainfall



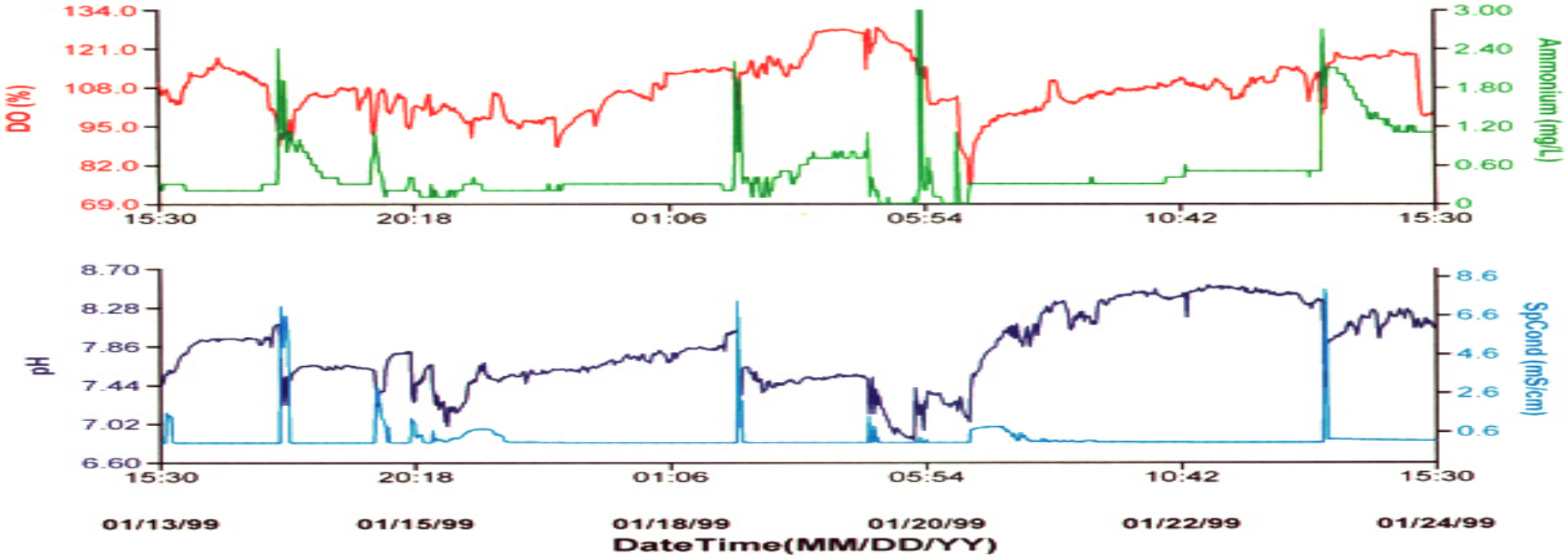
Top of Gulson Road



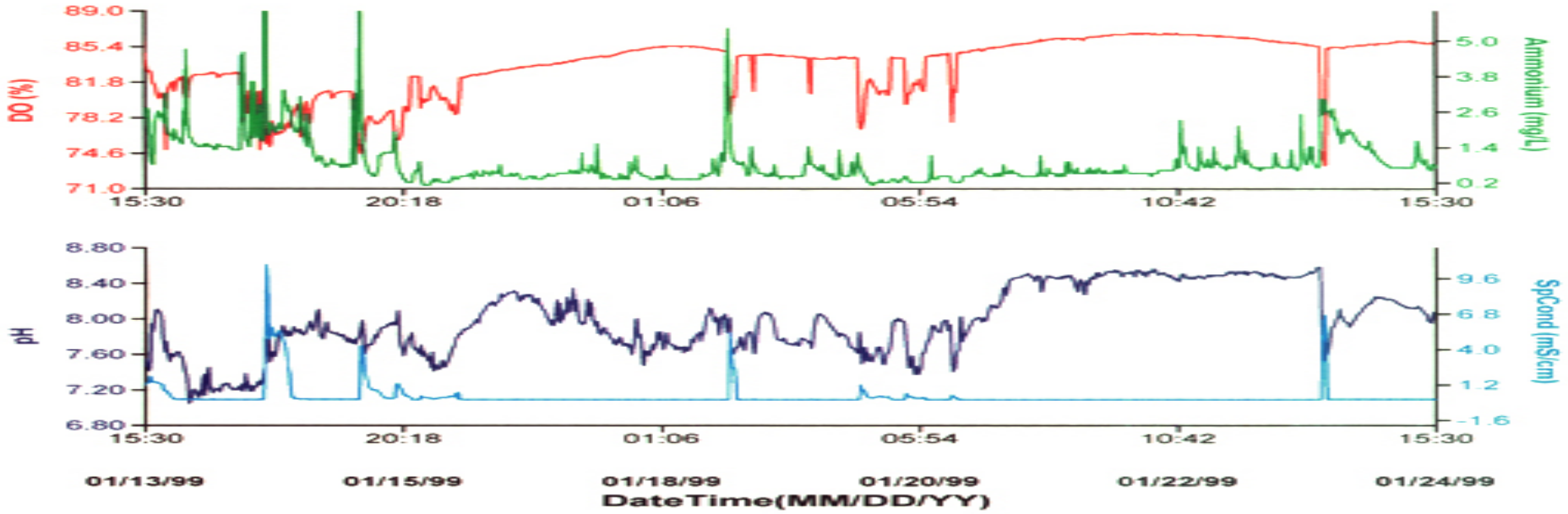
Swan Lane Culvert/ Gulson Road run 2. 13-24 January 1999
Finham Rainfall



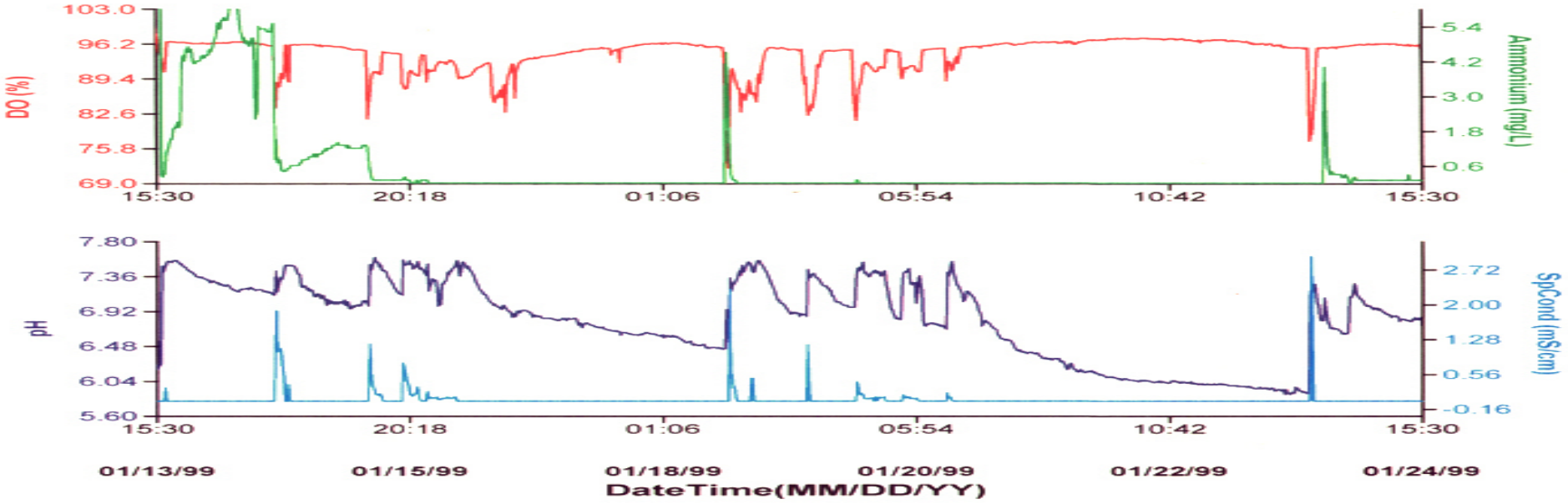
a)Top of Gulson Road



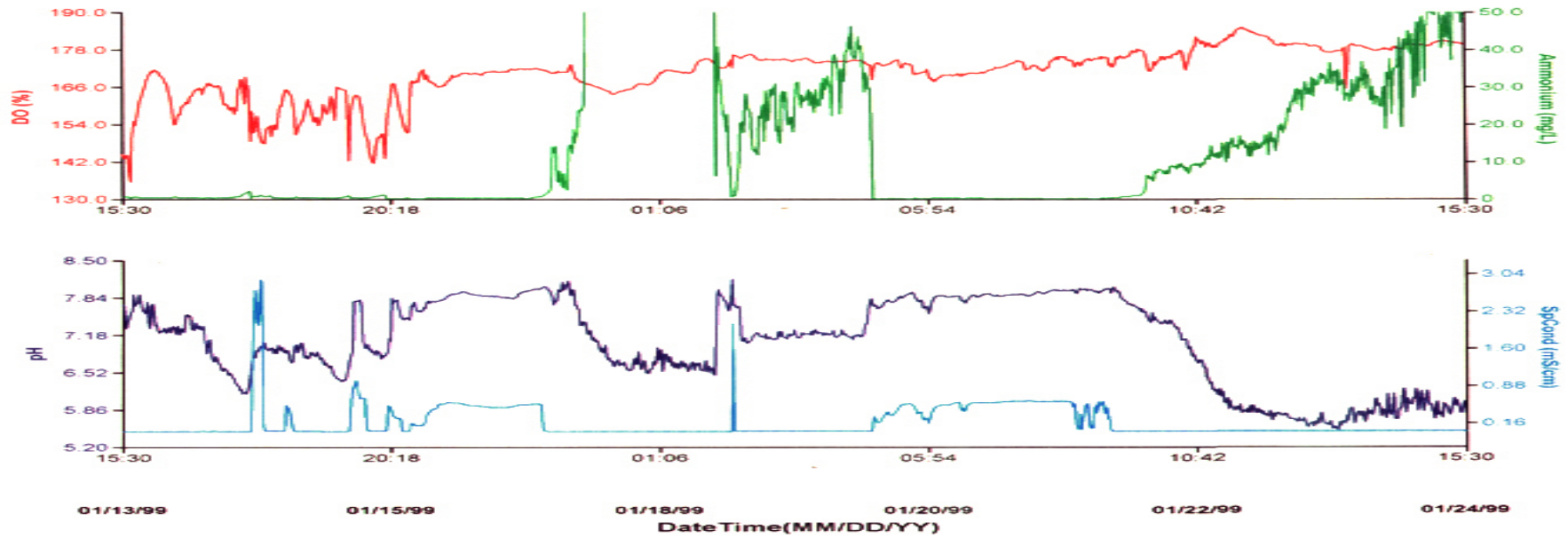
b) Gulson Road Manhole 799



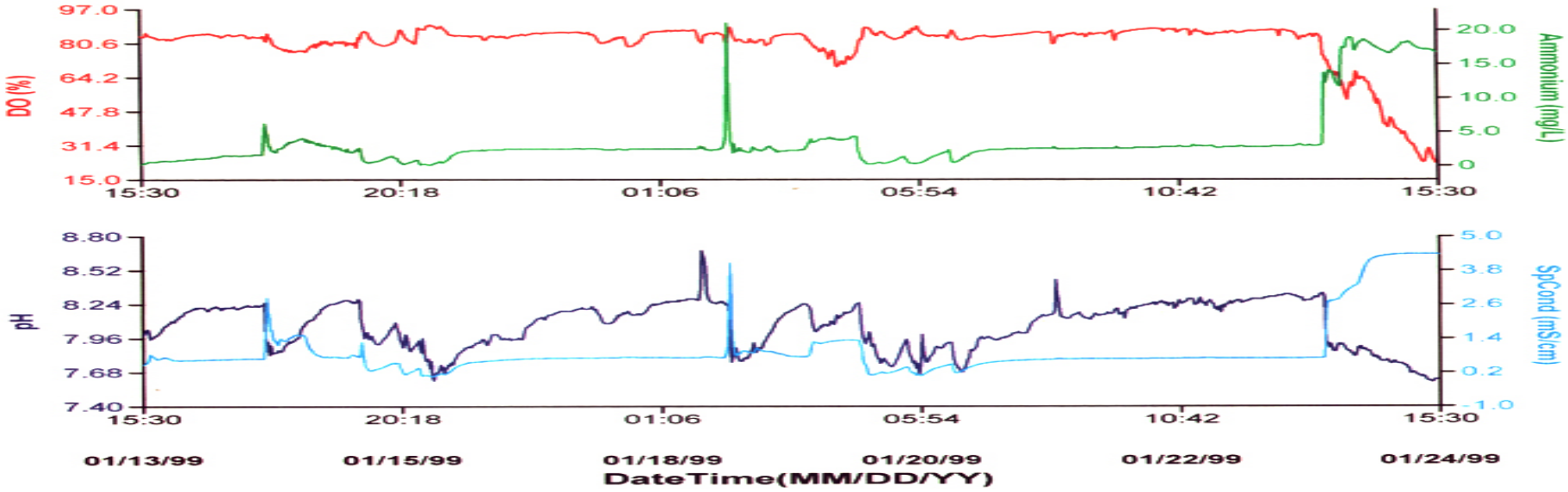
c) Clara Street



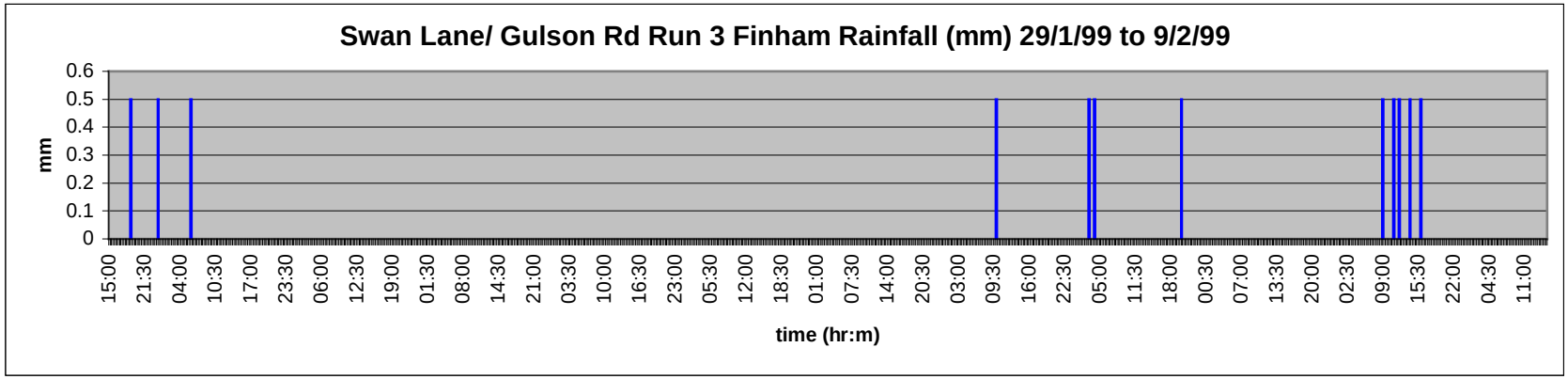
d) Swan Lane Culvert



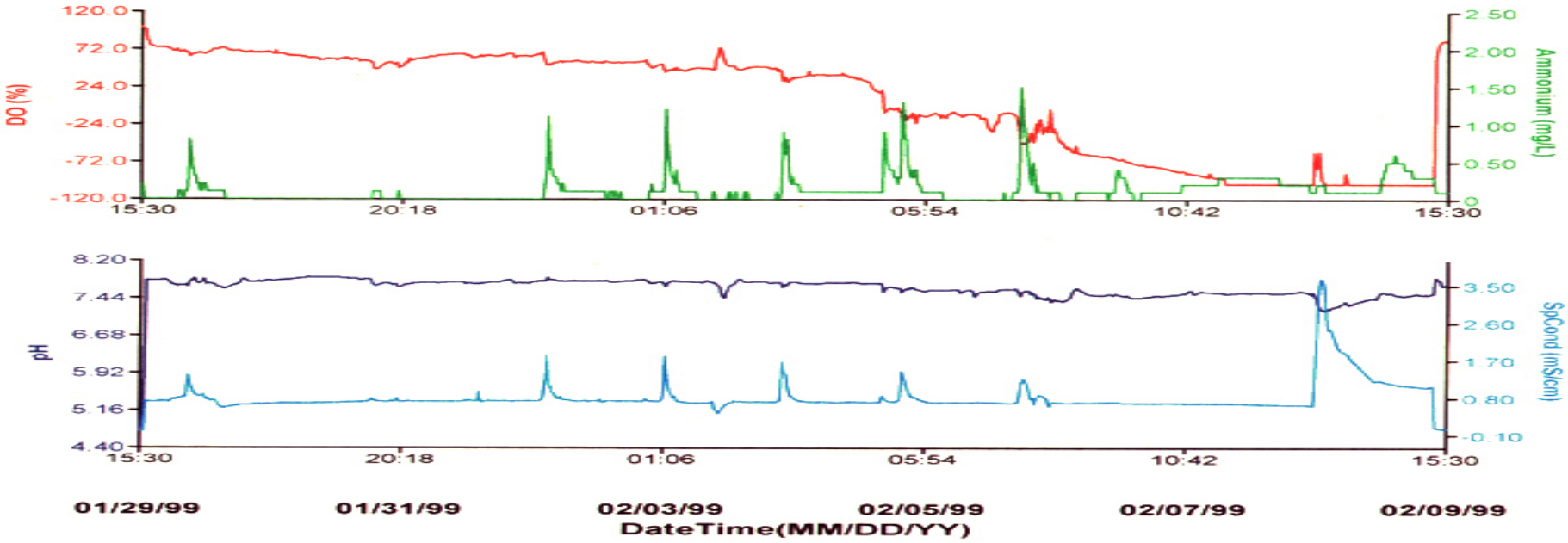
e) Swan Lane Culvert Hood Street



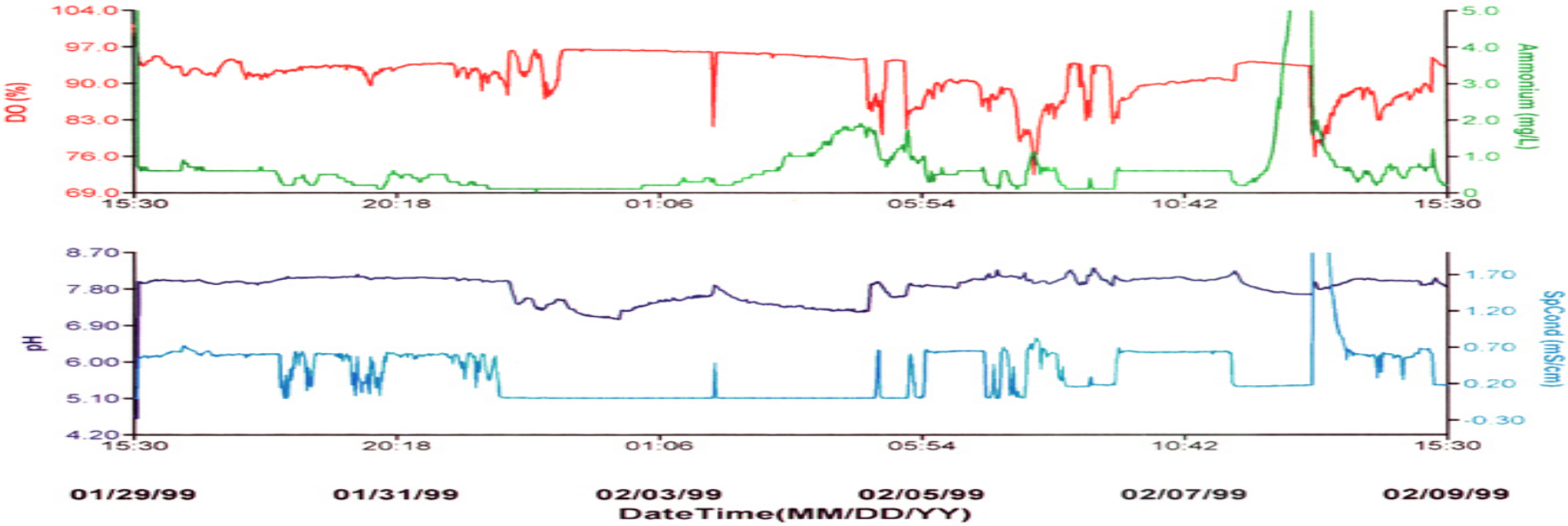
Swan Lane Culvert/ Gulson Road run 3. 29 January to 9 February 1999
Finham Rainfall



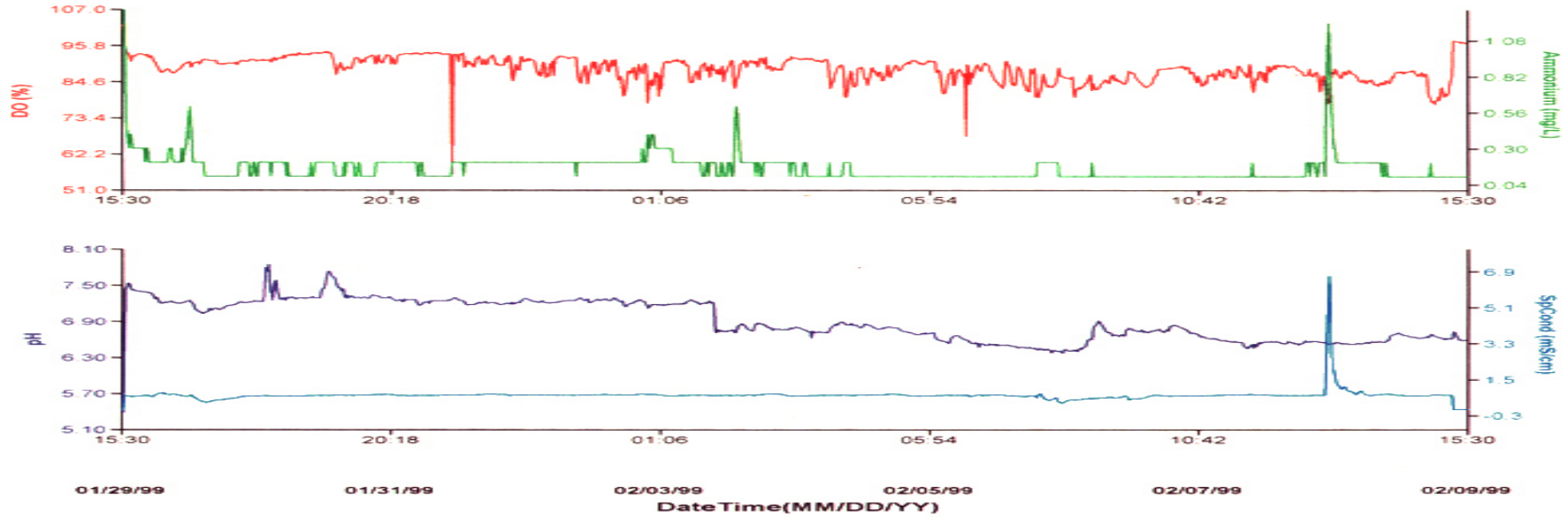
a) Swan Lane Culvert manhole 796



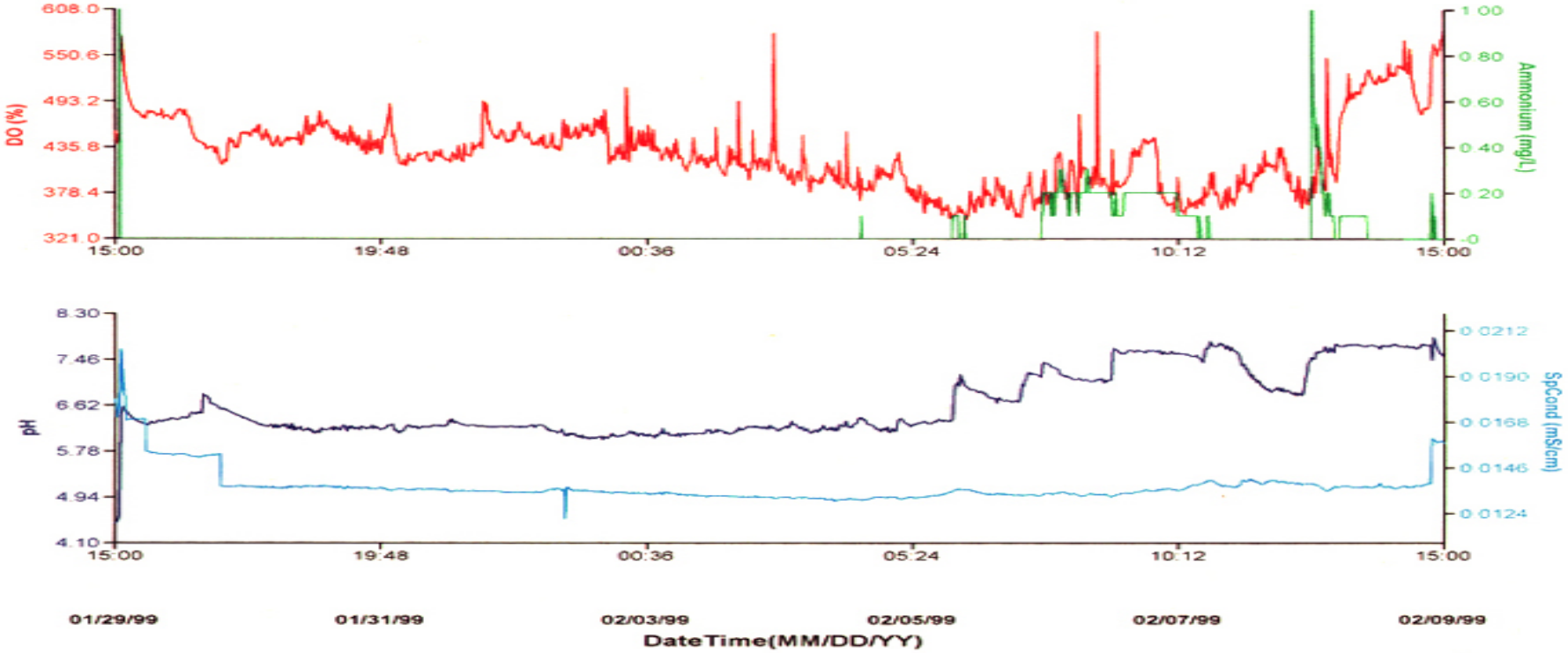
b) King Edward Road



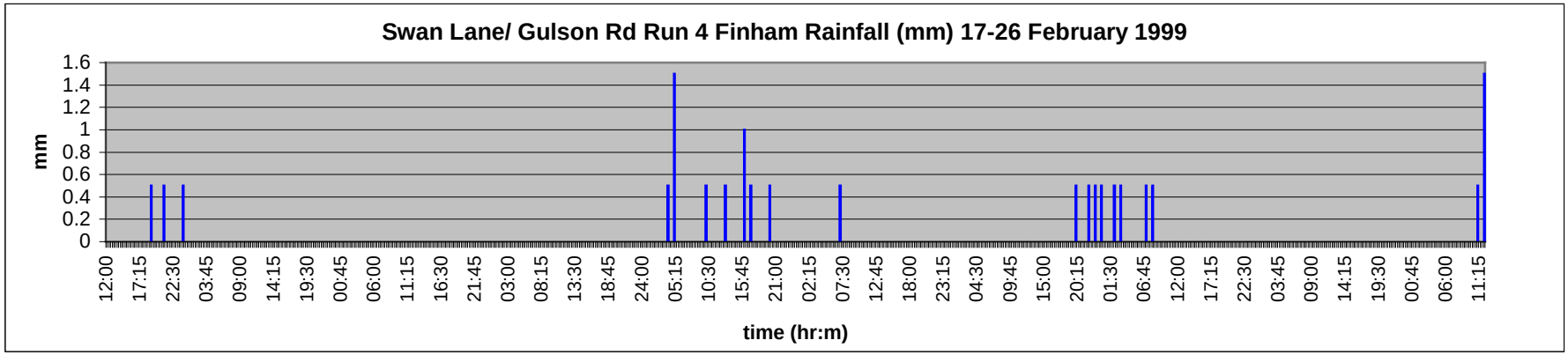
c) Swan Lane Culvert Berry Street



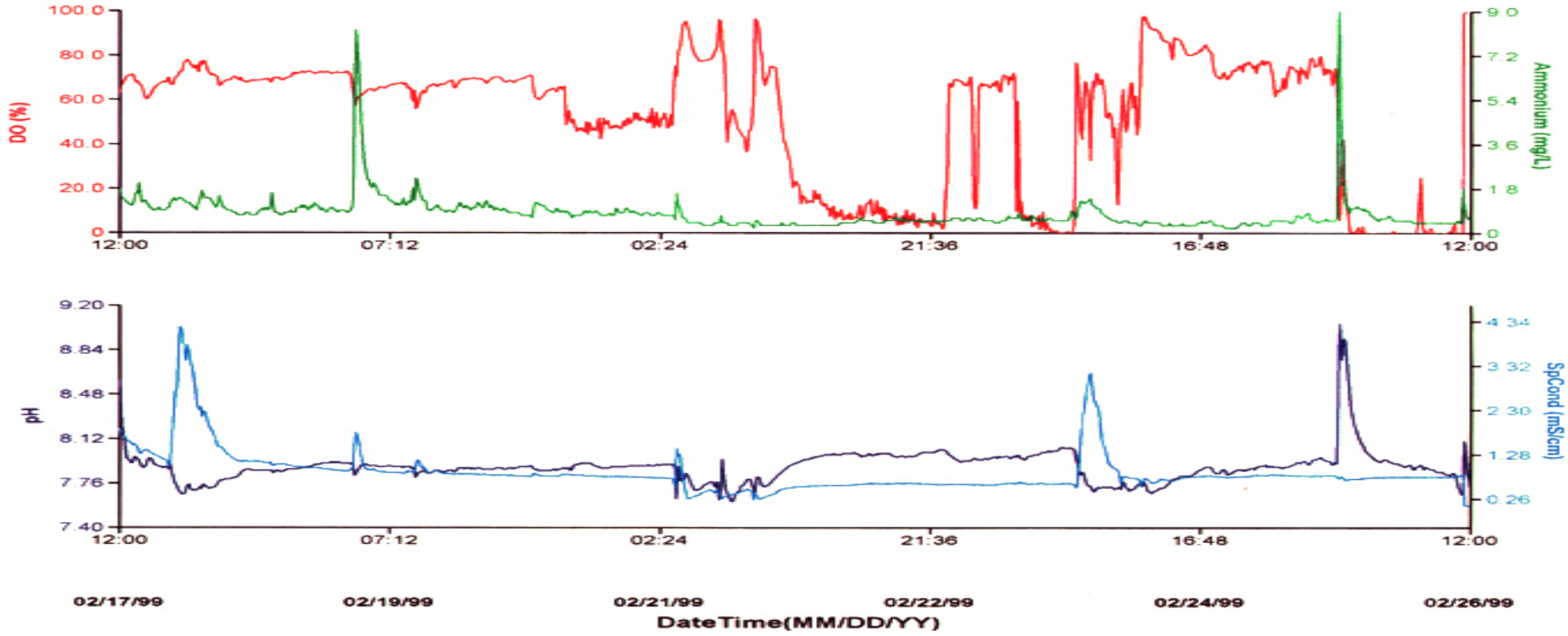
d) Swan Lane Culvert Hood Street manhole 201



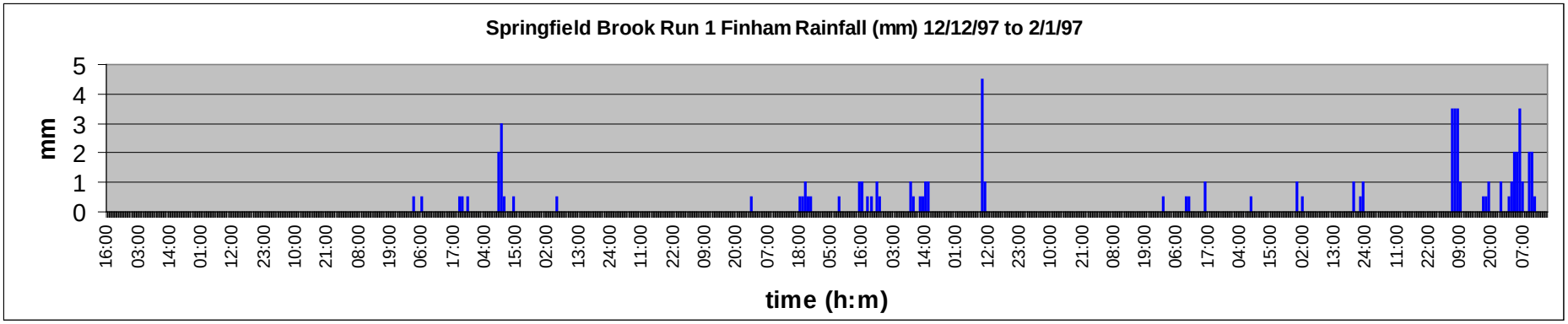
Swan Lane Culvert/ Gulson Road run 4. 17-26 February 1999
Finham Rainfall



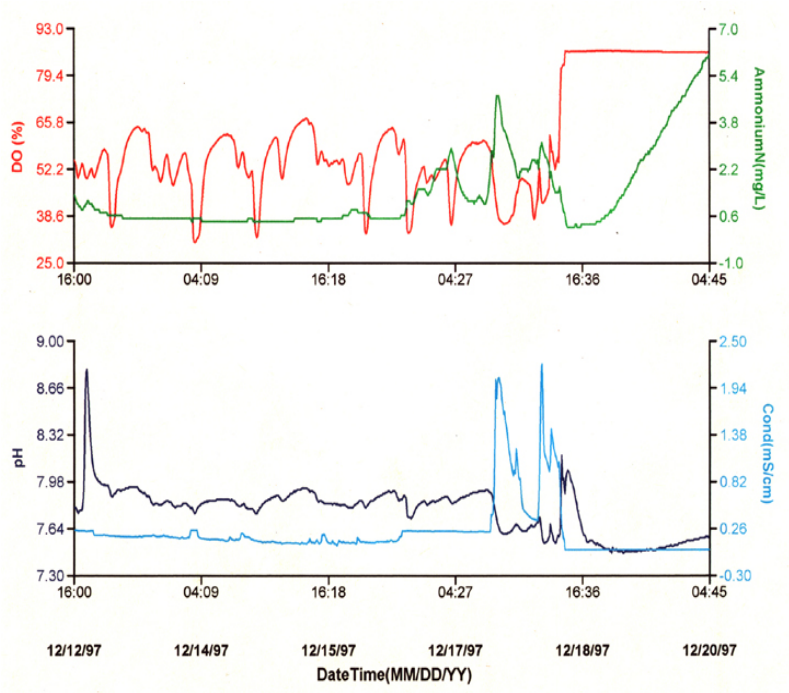
Swan Lane Culvert manhole 796



Springfield brook run1 12 December 1997 to 2 February 1998
Finham Rainfall

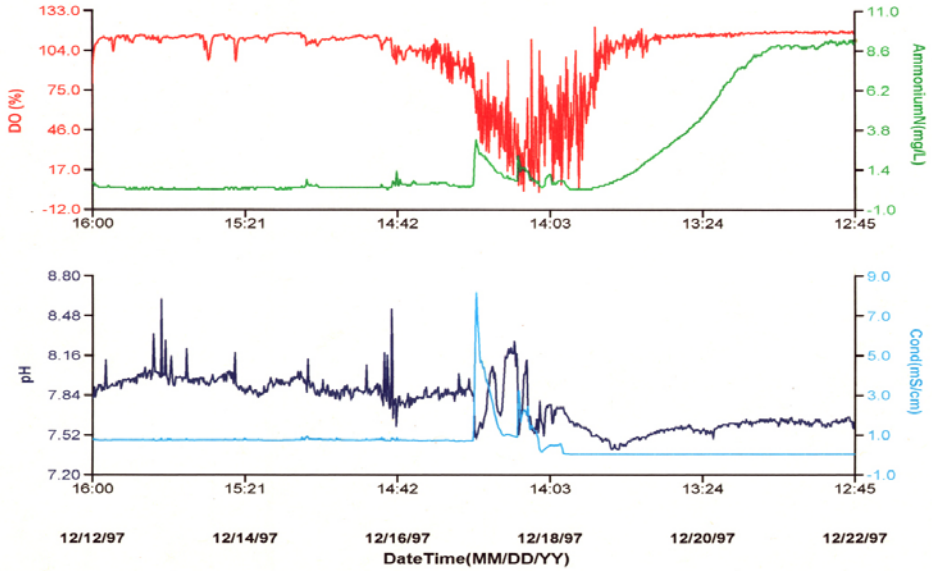


a) Bowness Close



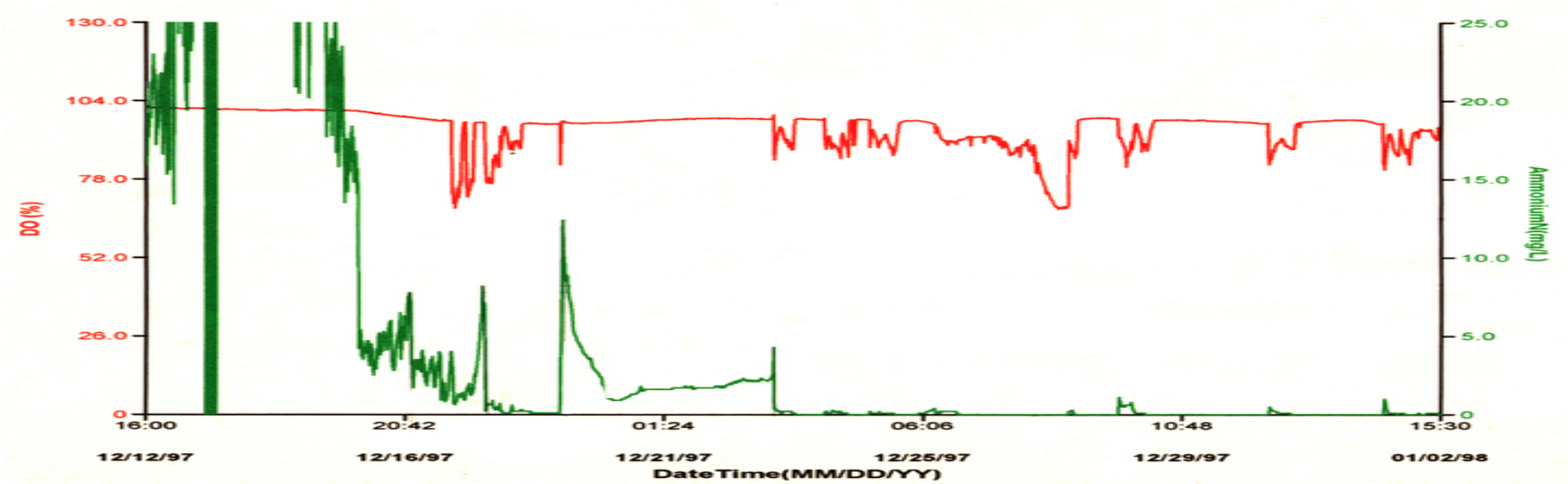
Data period for this site is 12-20 December only

b)Christopher Cash School

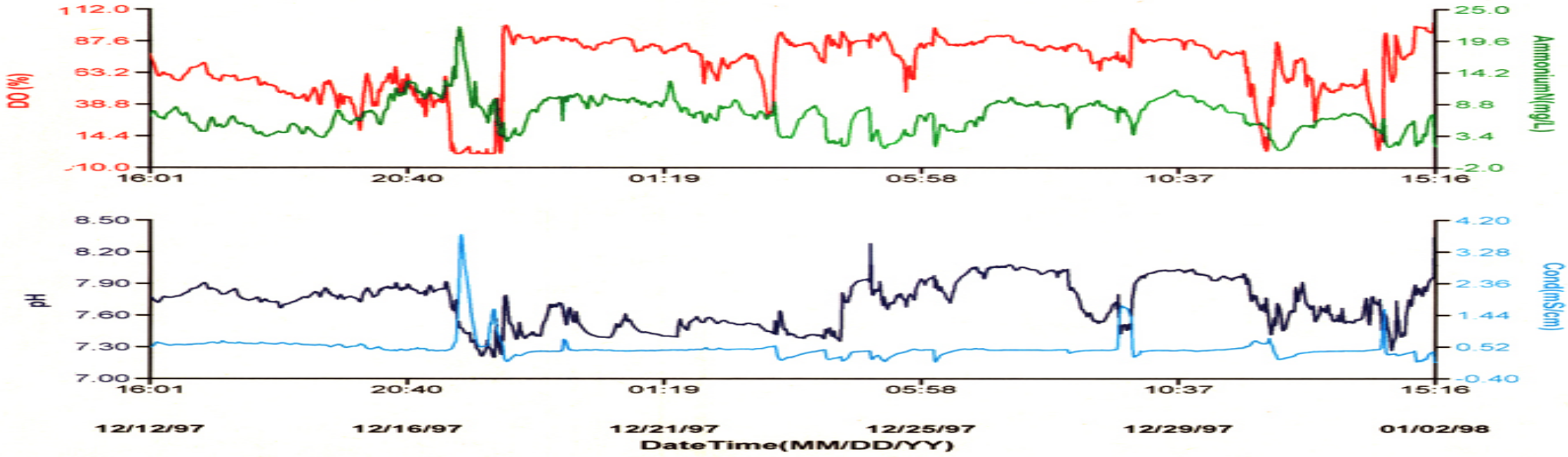


Data period for this site is 12-22 December only

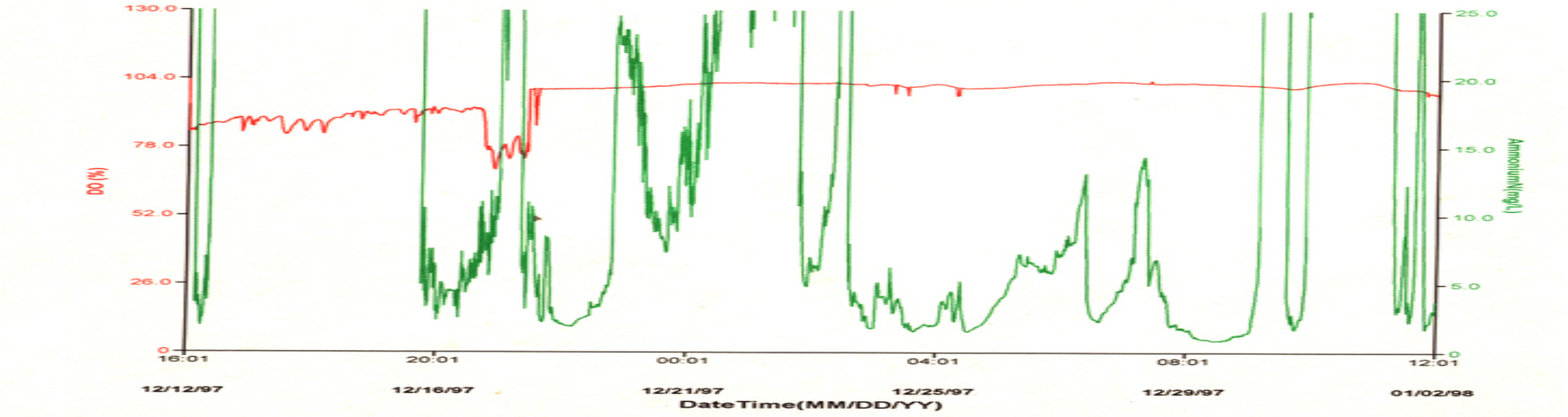
c) Courtaulds



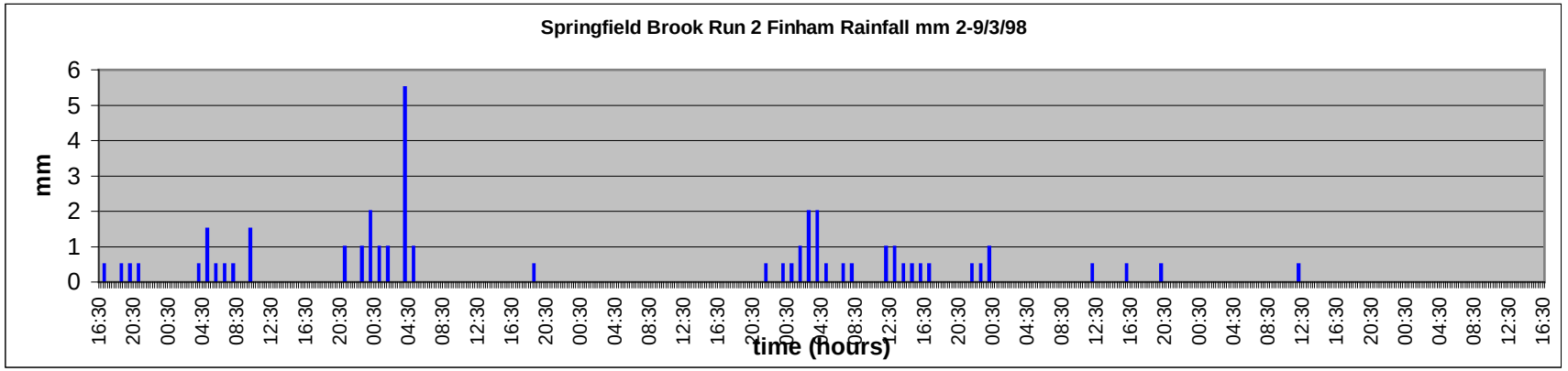
d) Cash's Lane



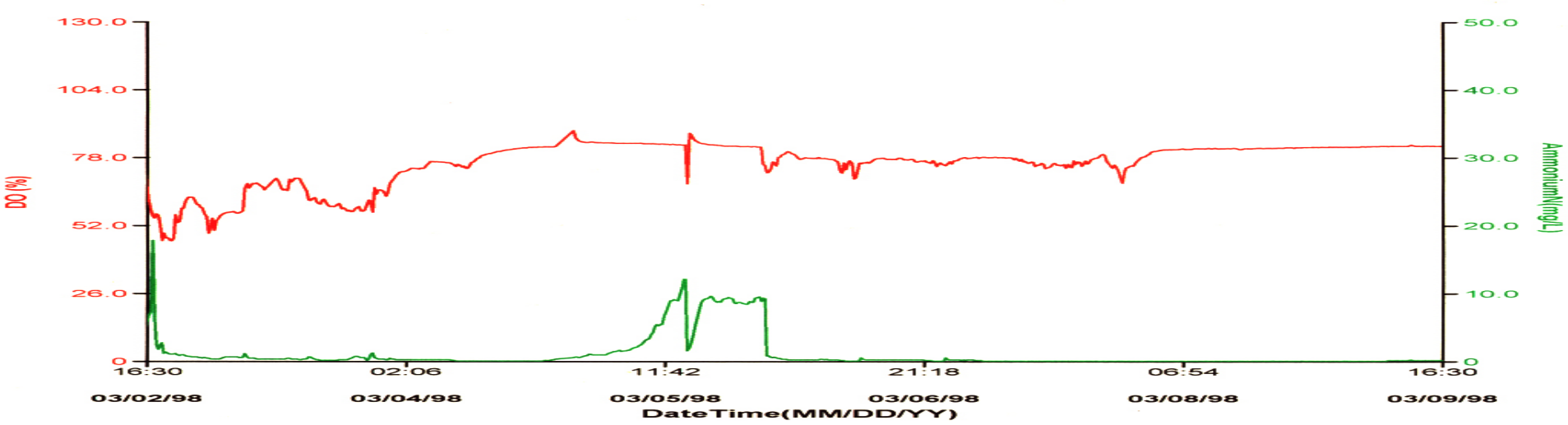
e) Planet Carpark



Springfield brook run2 2 –9 March 1998
Finham Rainfall

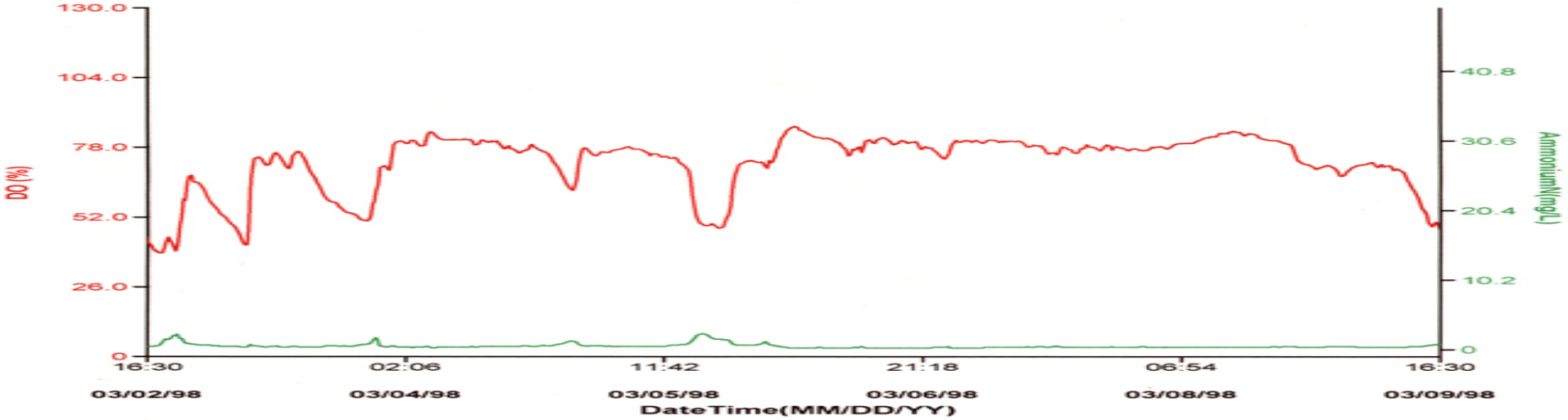


a) Courtaulds

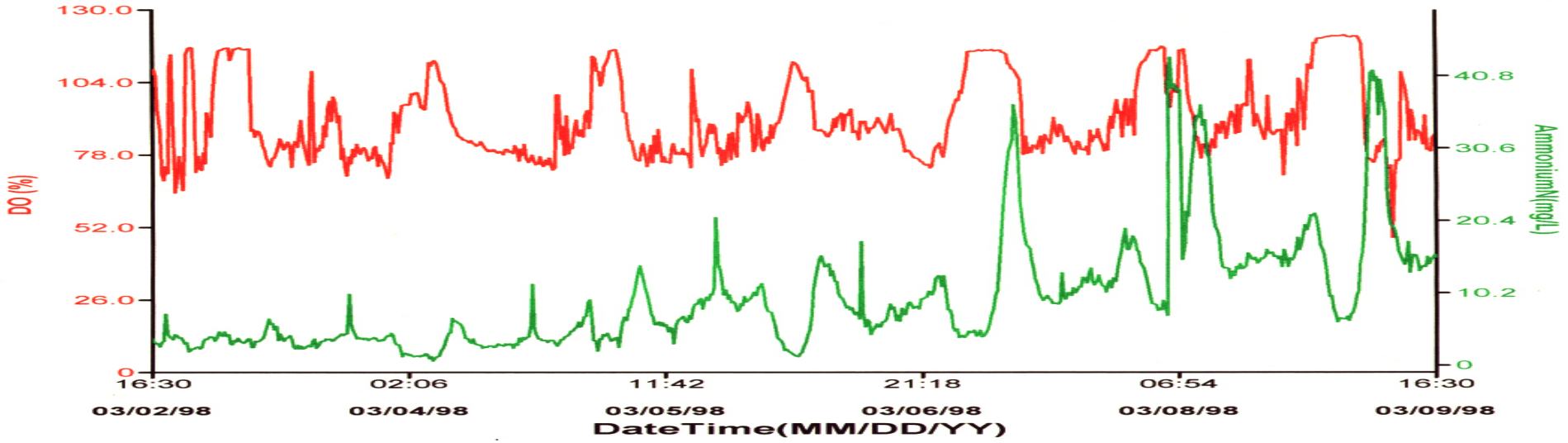


Springfield brook run2 2 –9 March 1998

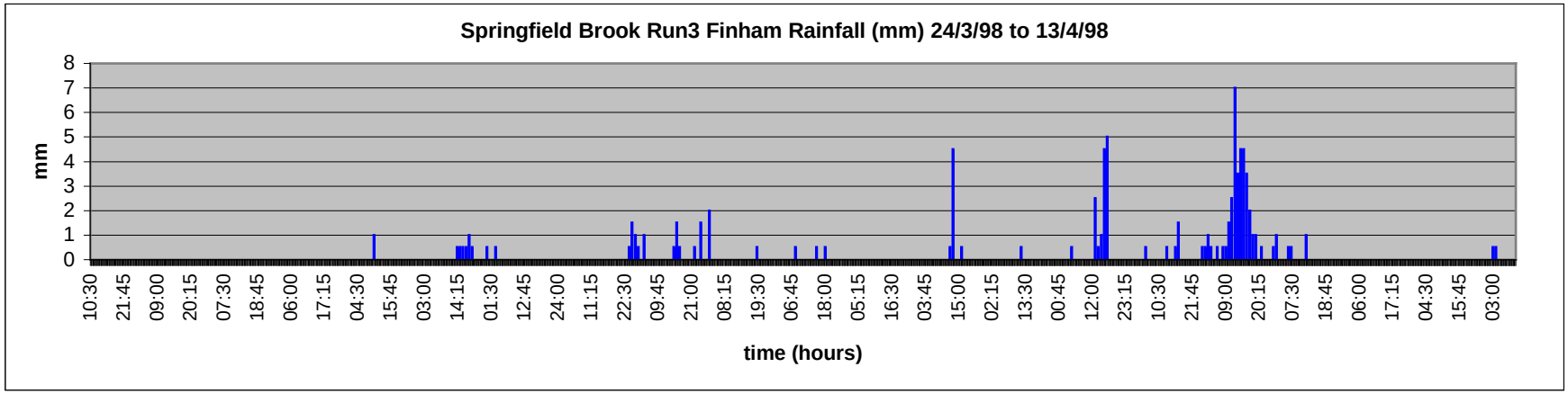
b) Cash's Lane



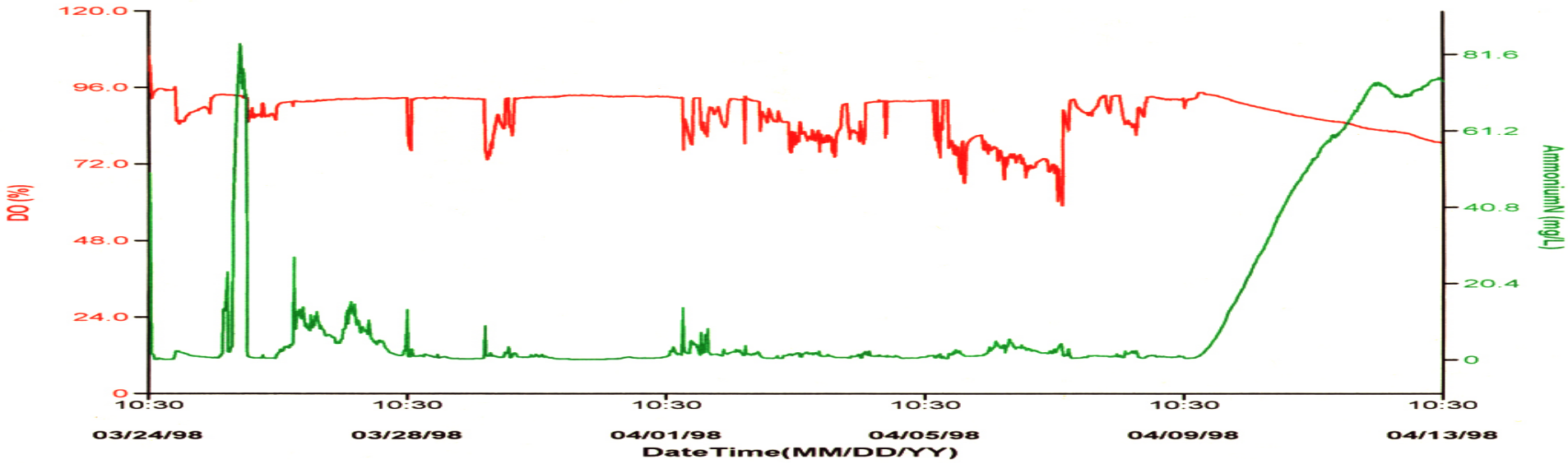
c) Springfield Place



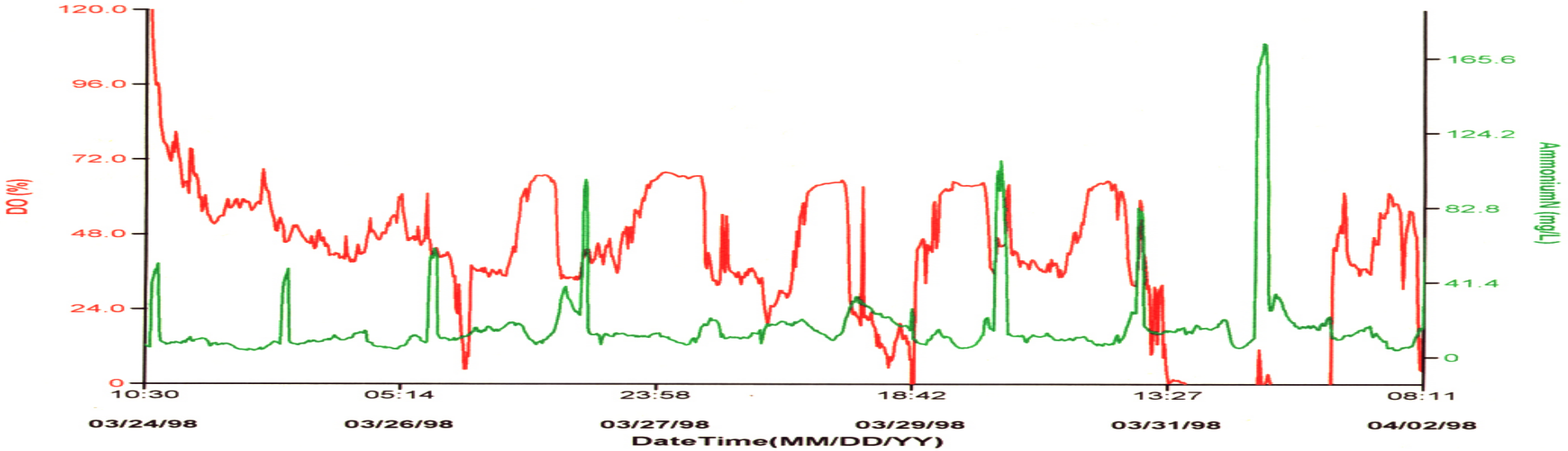
Springfield brook run3 24 March to 2 April 1998
Finham Rainfall



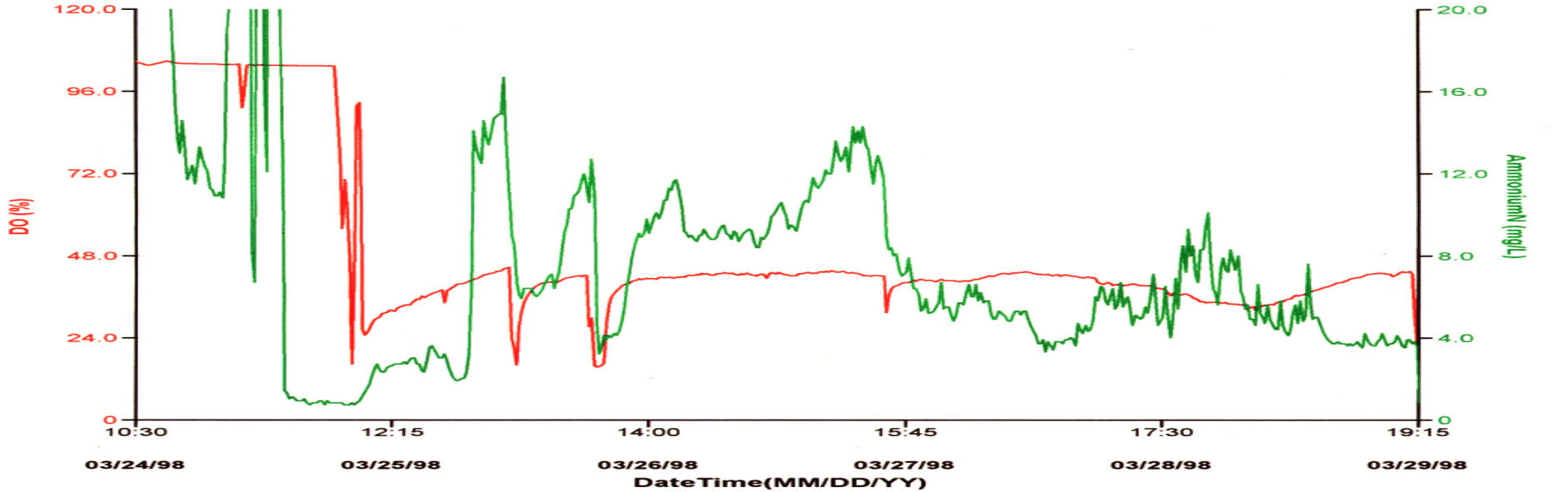
a) Courtaulds



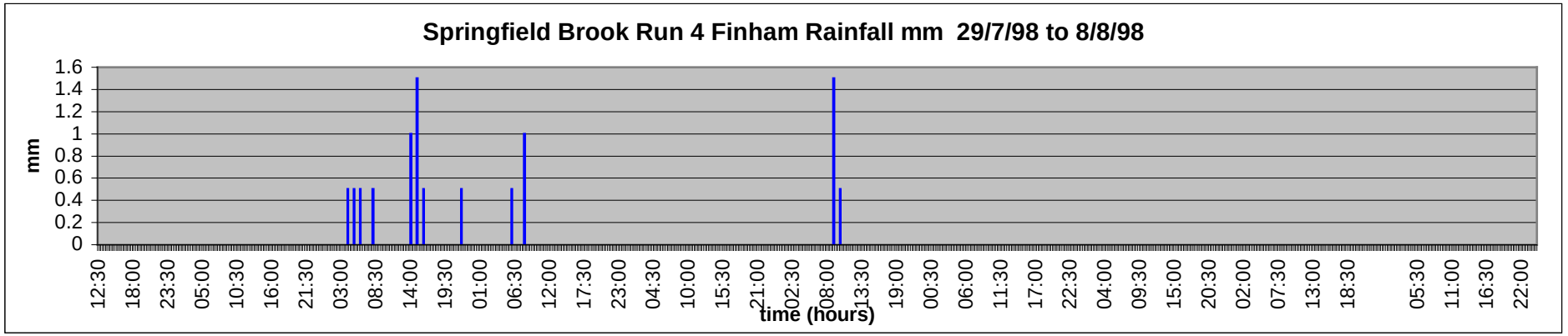
b) Springfield Place



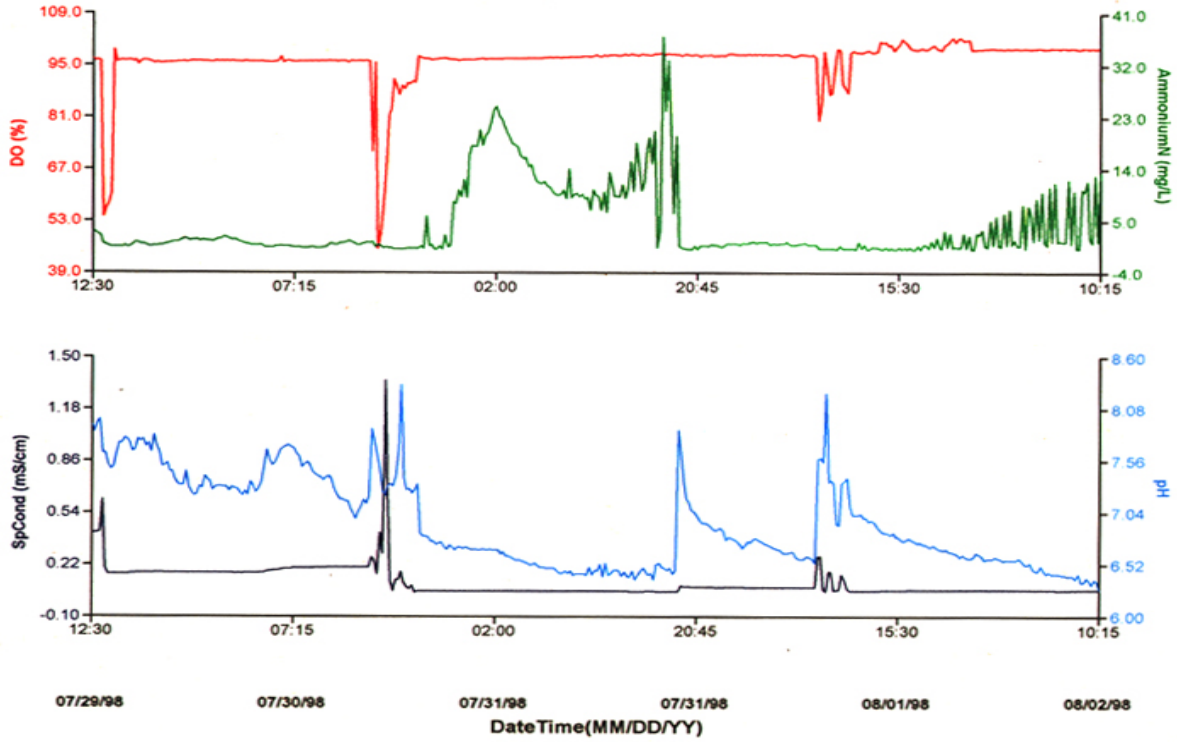
c) Planet Carpark



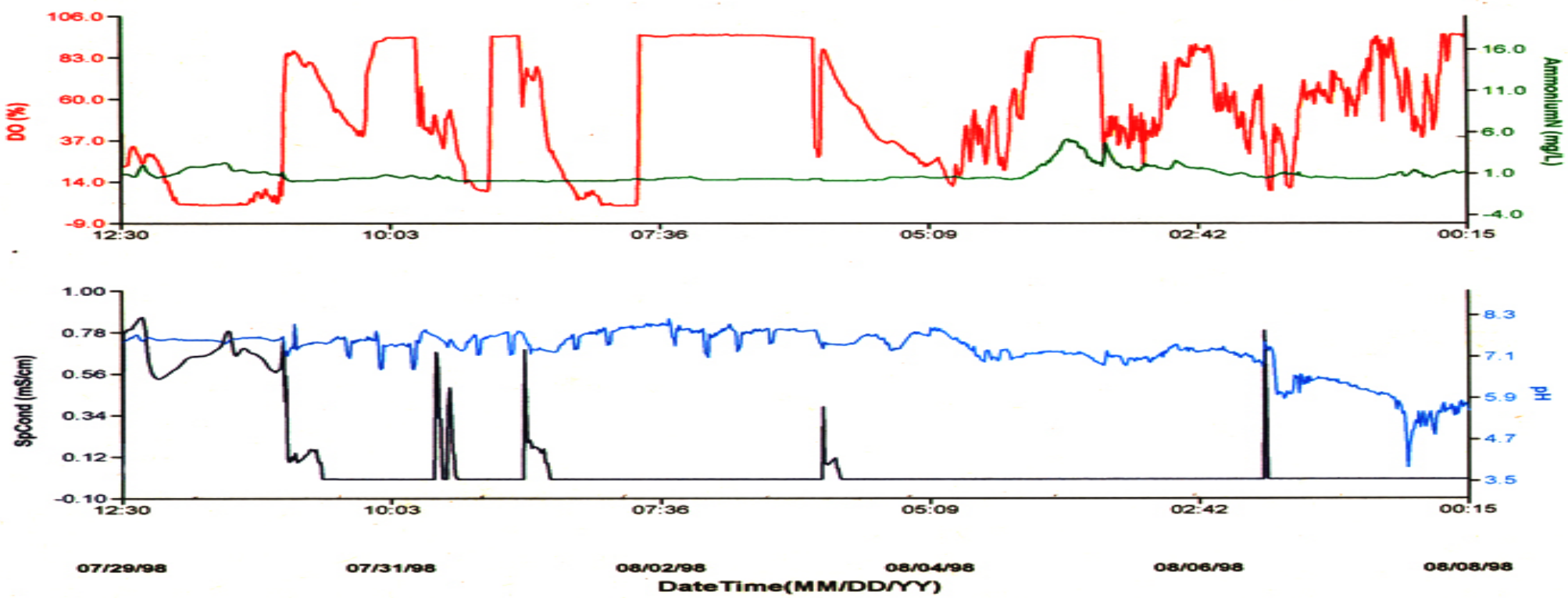
Springfield brook run4 29 July to 2 August 1998
Finham Rainfall



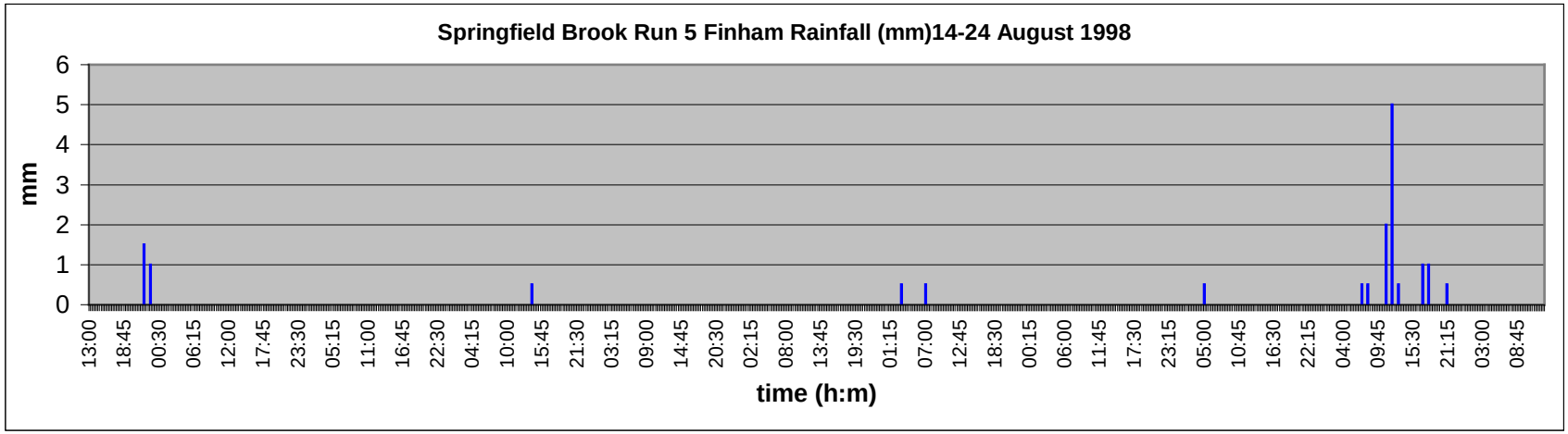
a) **Courtaulds**



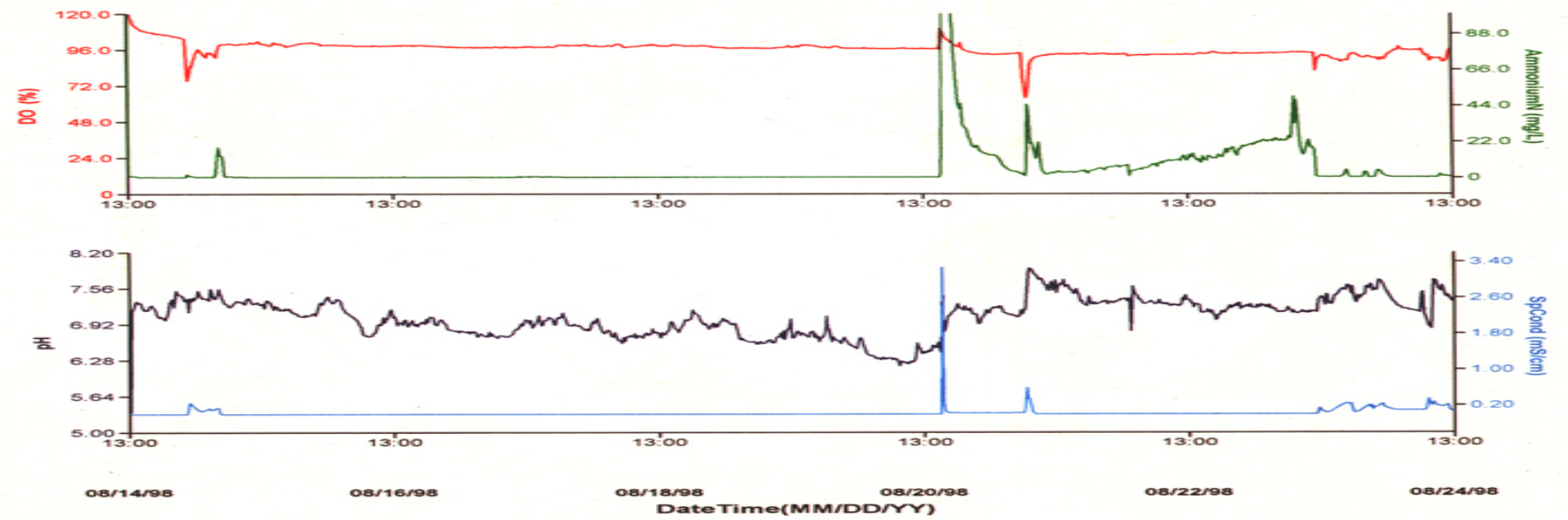
a) Cash's Lane


DO (%)
106.0
83.0
60.0
37.0
14.0
-9.0
AmmoniumN (mg/L)
16.0
11.0
6.0
1.0
-4.0
12:30
10:03
07:36
05:09
02:42
00:15
SpCond (mS/cm)
1.00
0.78
0.56
0.34
0.12
-0.10
pH
8.3
7.1
5.9
4.7
3.5
07/29/98
07/31/98
08/02/98
08/04/98
08/06/98
08/08/98
DateTime(MM/DD/YY)

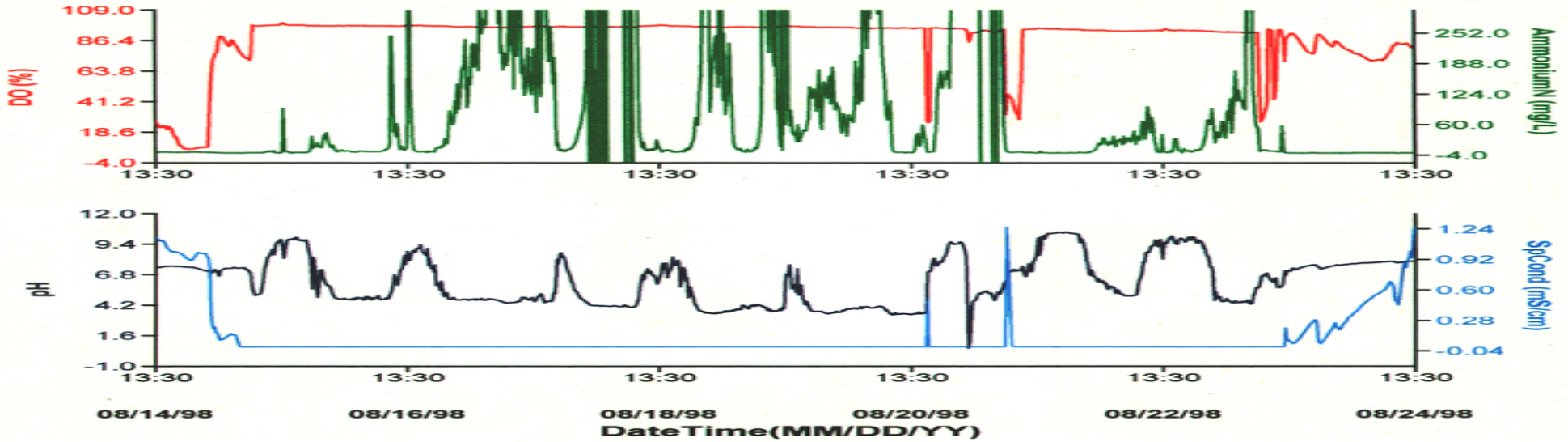
Springfield brook run5 14 -24 August 1998
Finham Rainfall



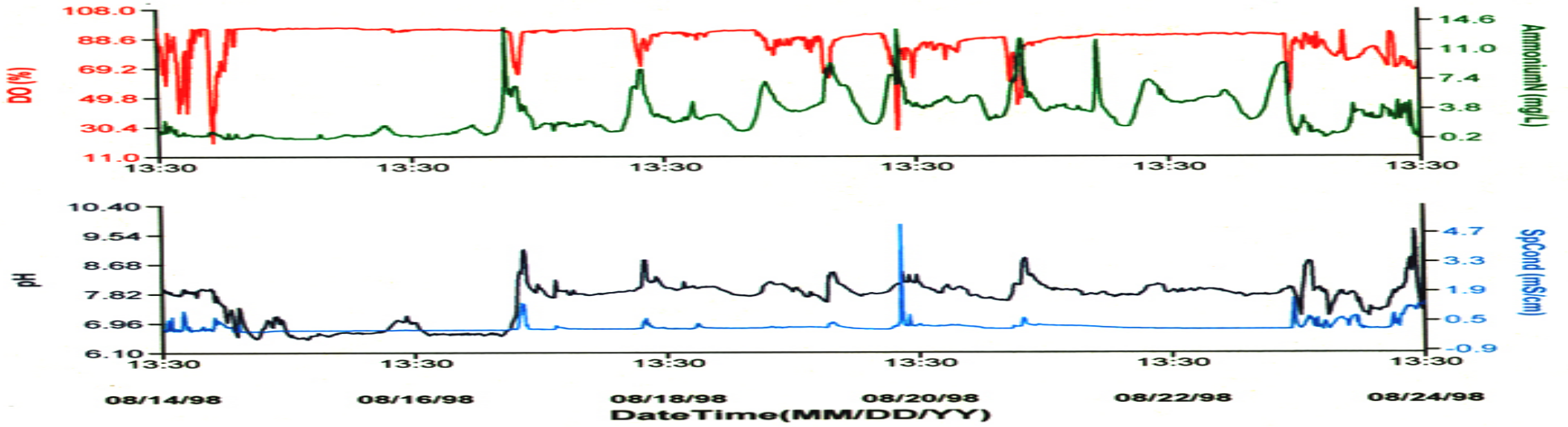
a) Courtaulds manhole 891



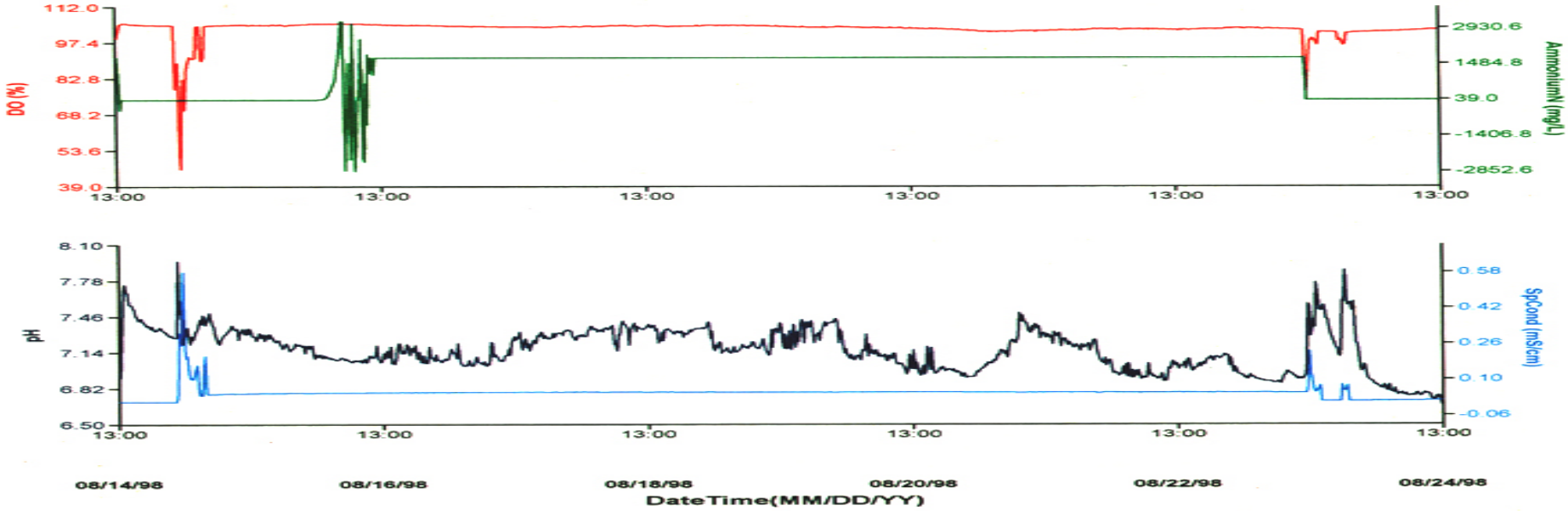
b) Cash's Lane



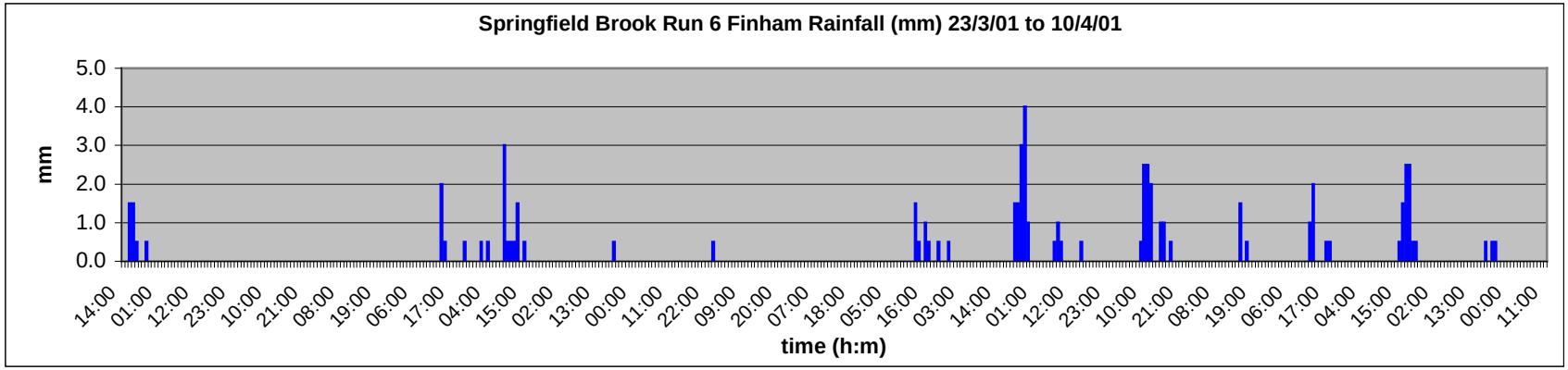
c) Springfield Place manhole 6999



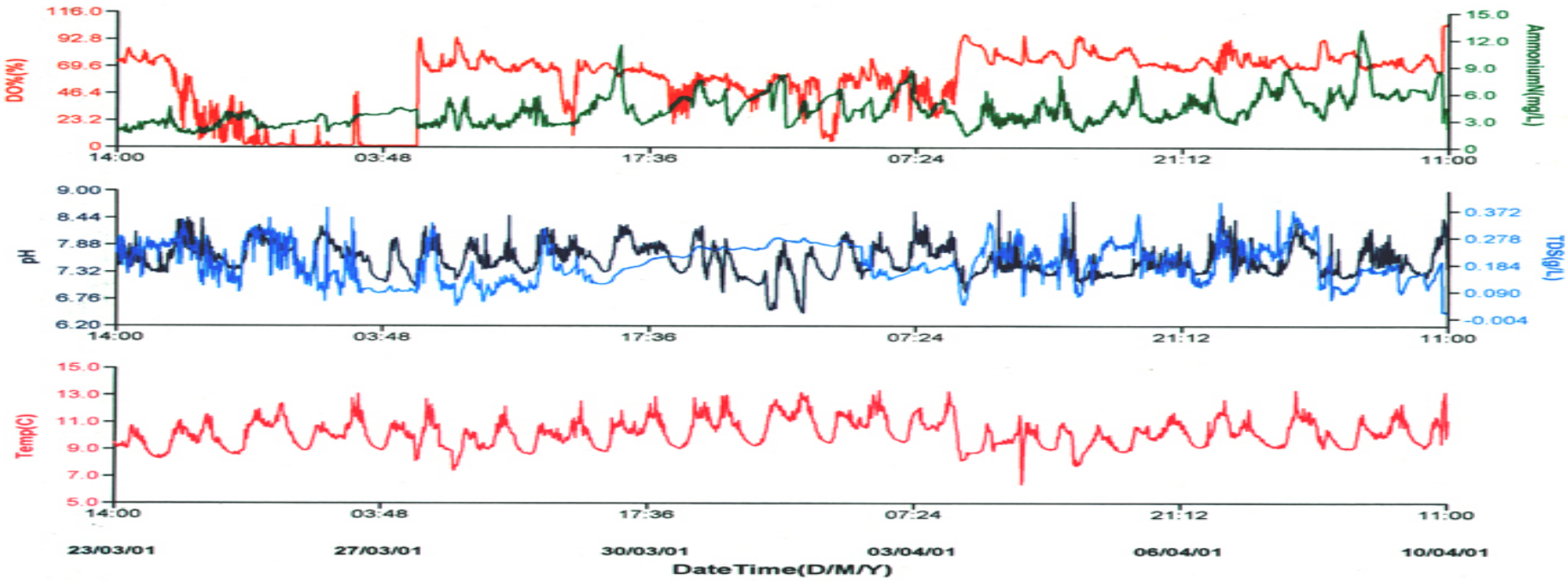
d) Planet Carpark



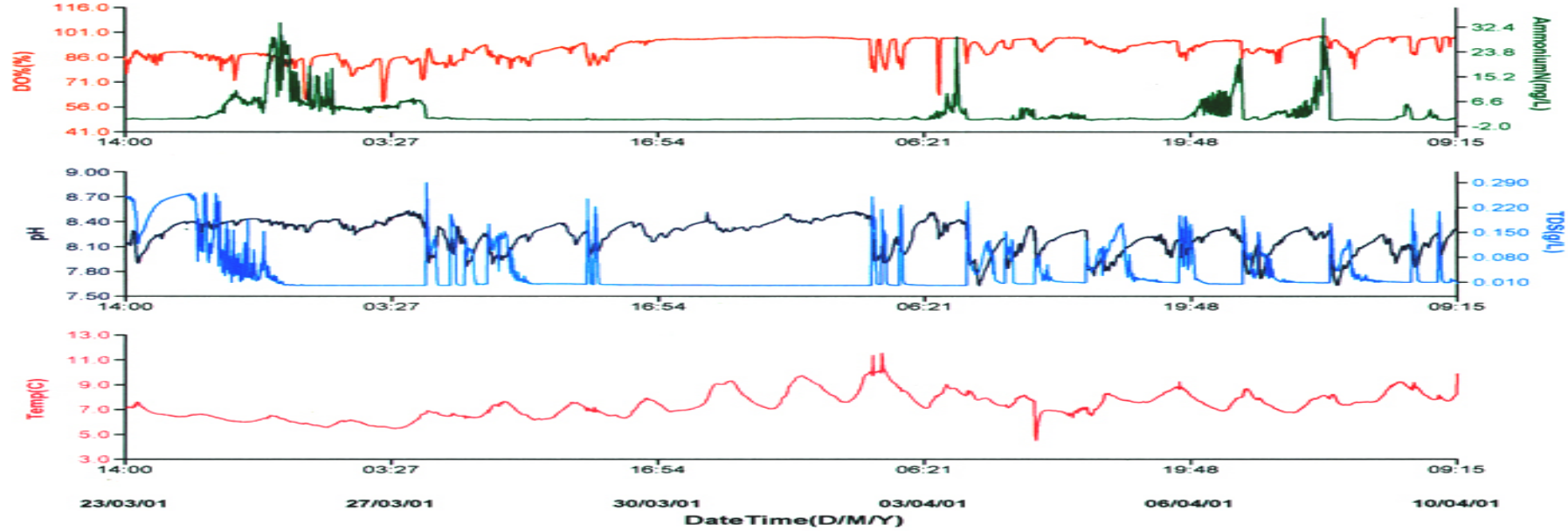
Springfield brook run6 23 March to 10 April 2001
Finham Rainfall



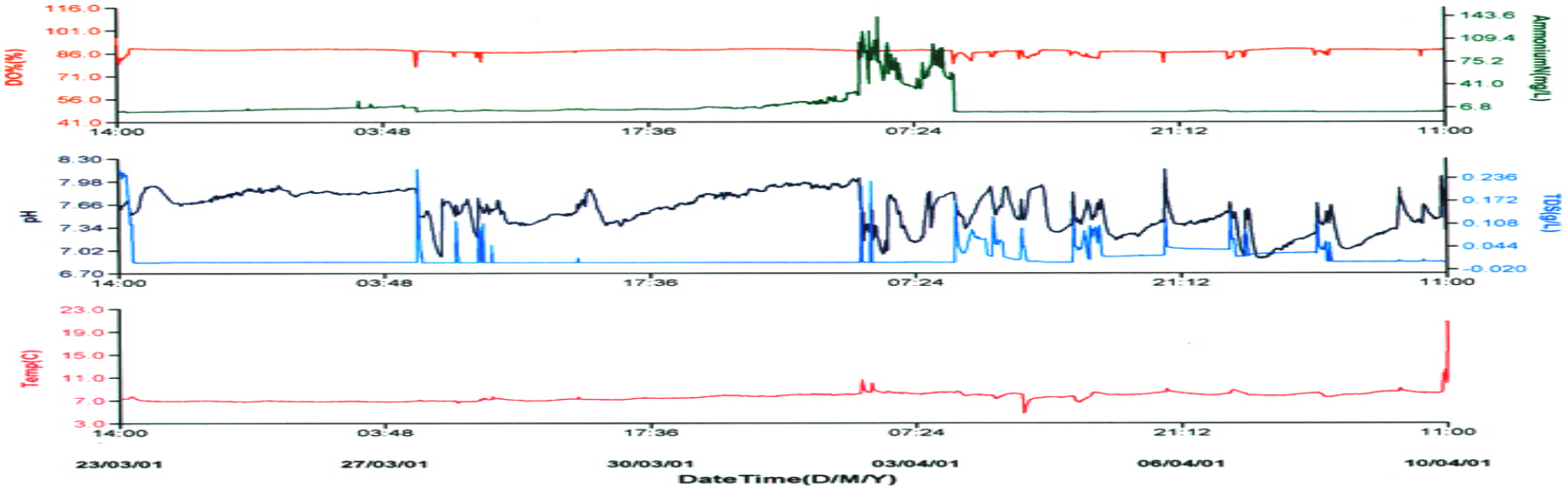
a) Springfield Brook Dickens Rd



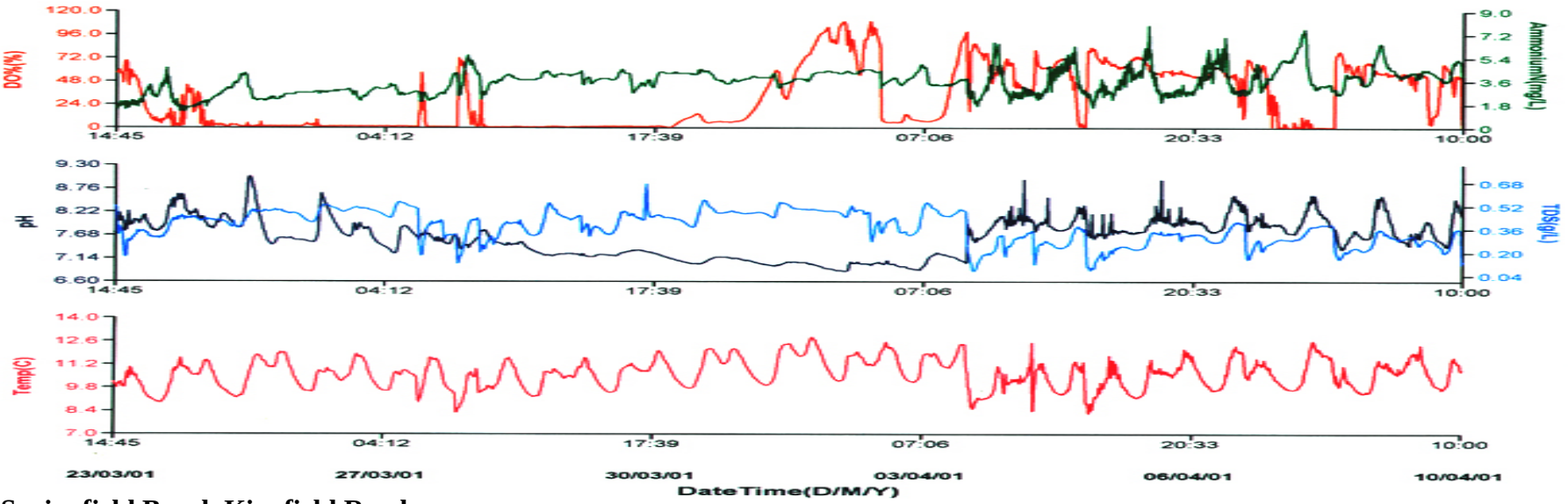
b) Springfield Brook Borrowdale Close



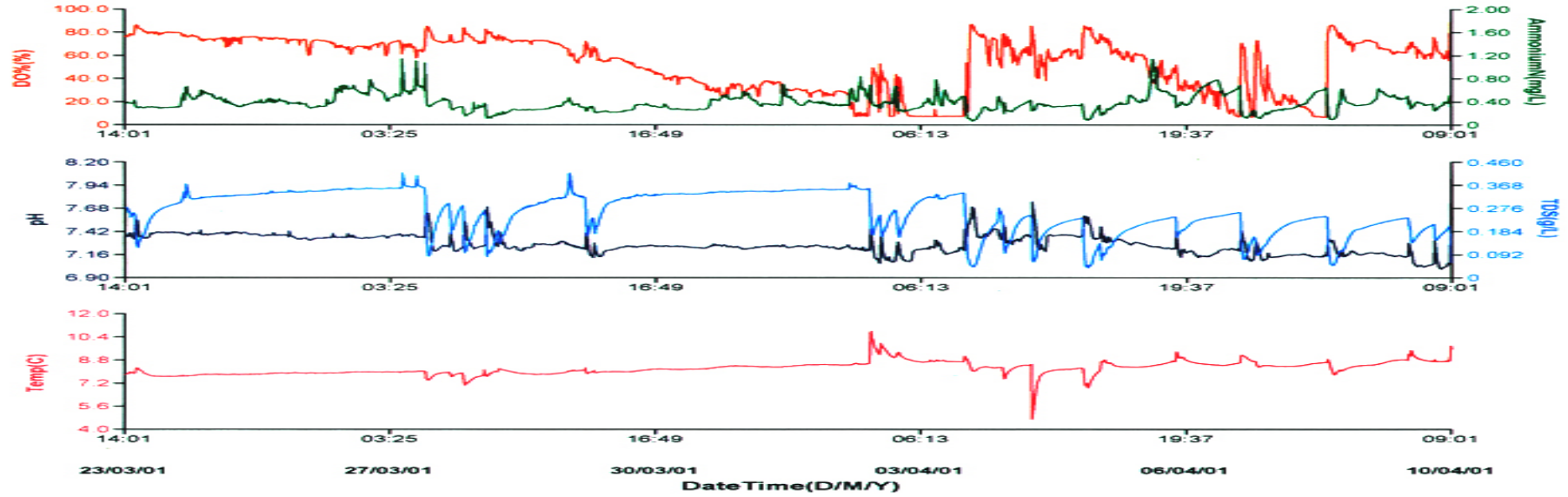
c) Springfield Brook Guardhouse lane



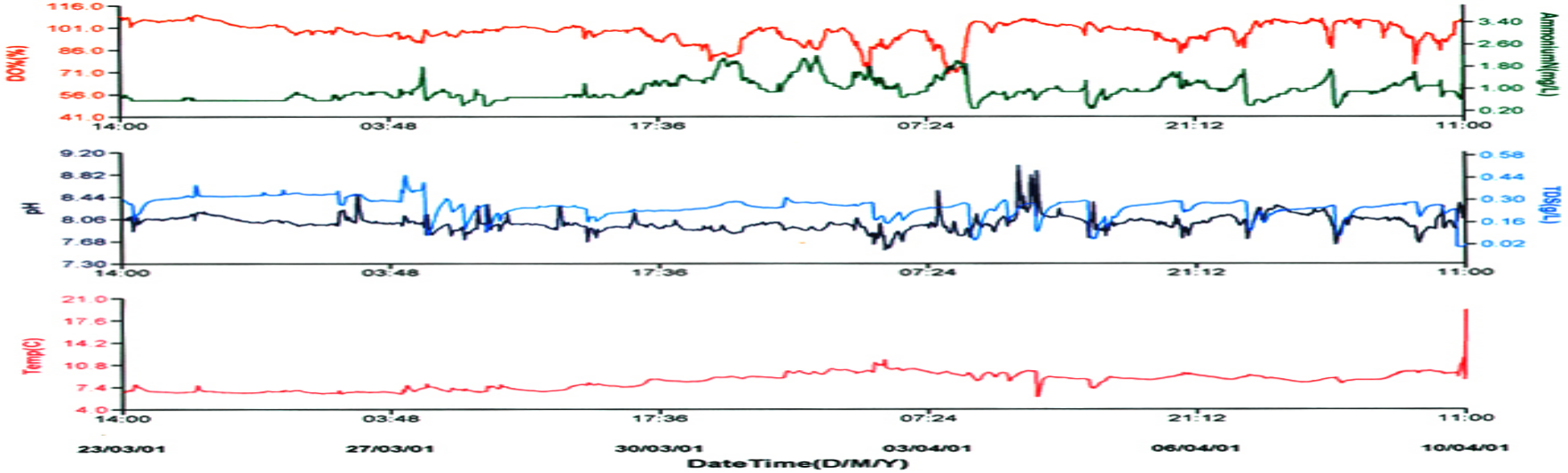
d) Springfield Brook Owenford Road



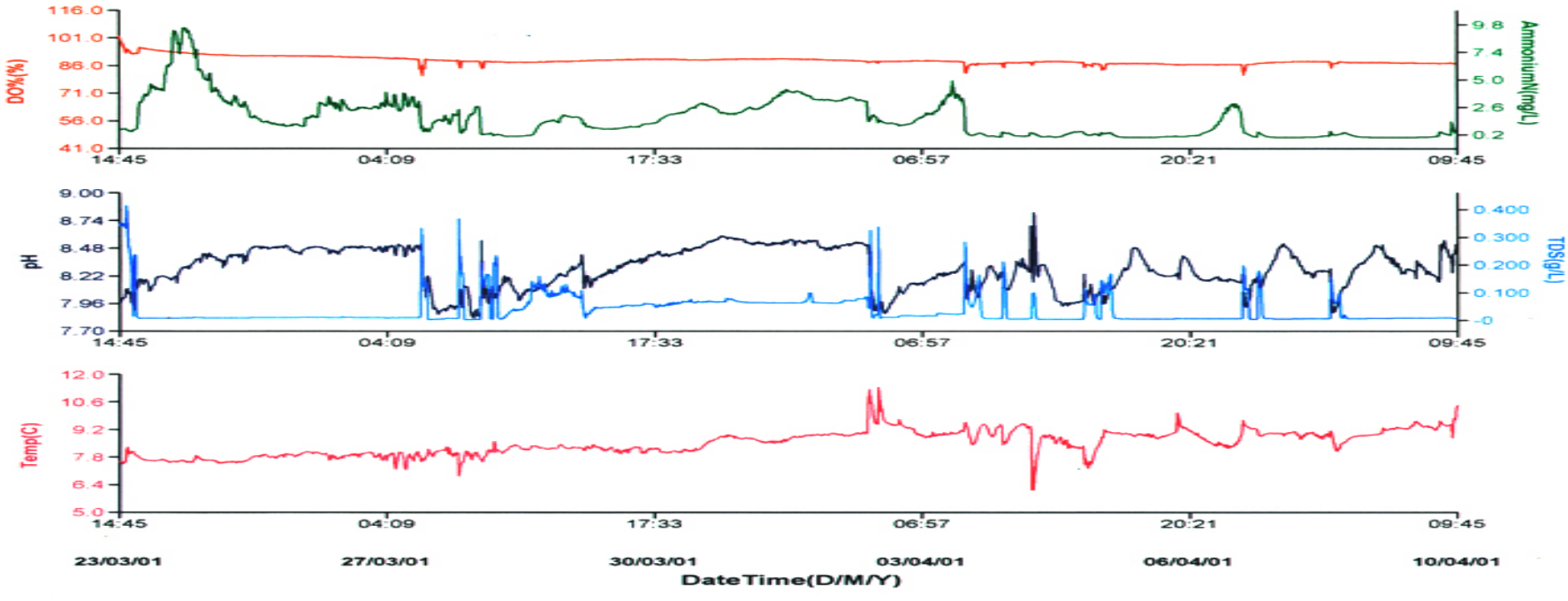
e) Springfield Brook Kingfield Road



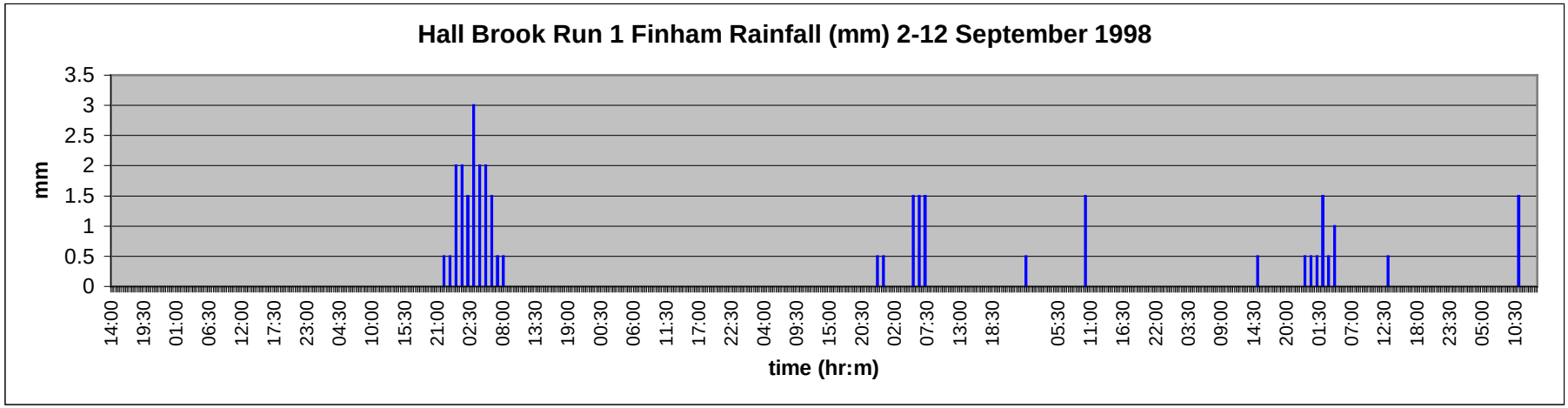
f) Springfield Brook Cash's Lane



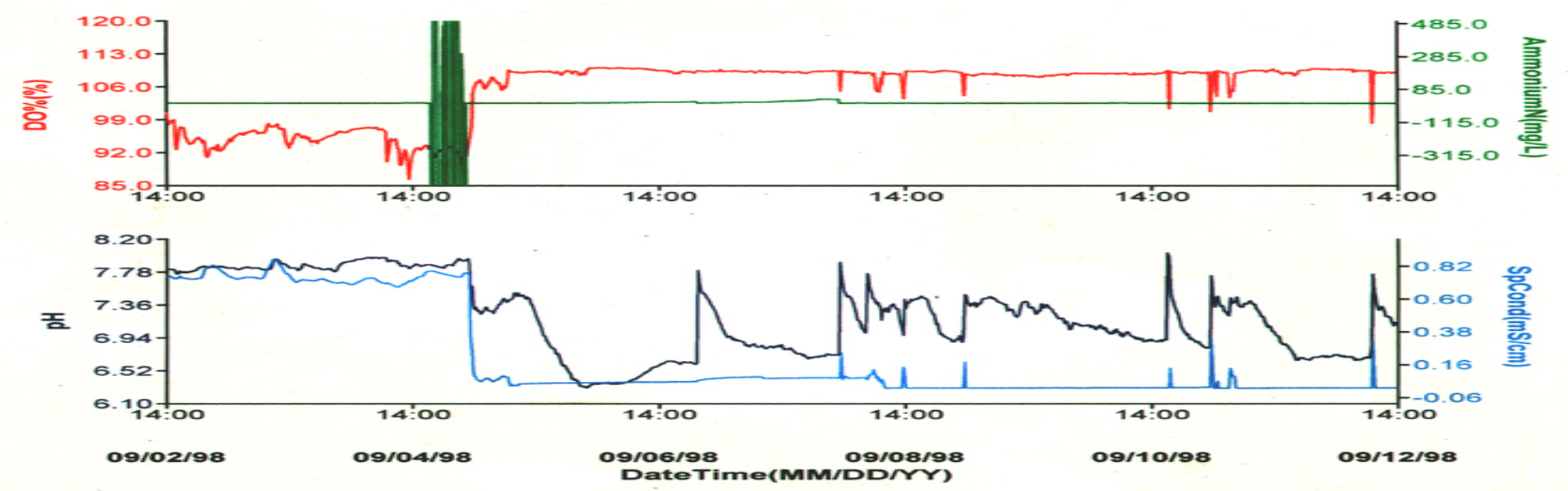
g) Springfield Brook Planet Carpark



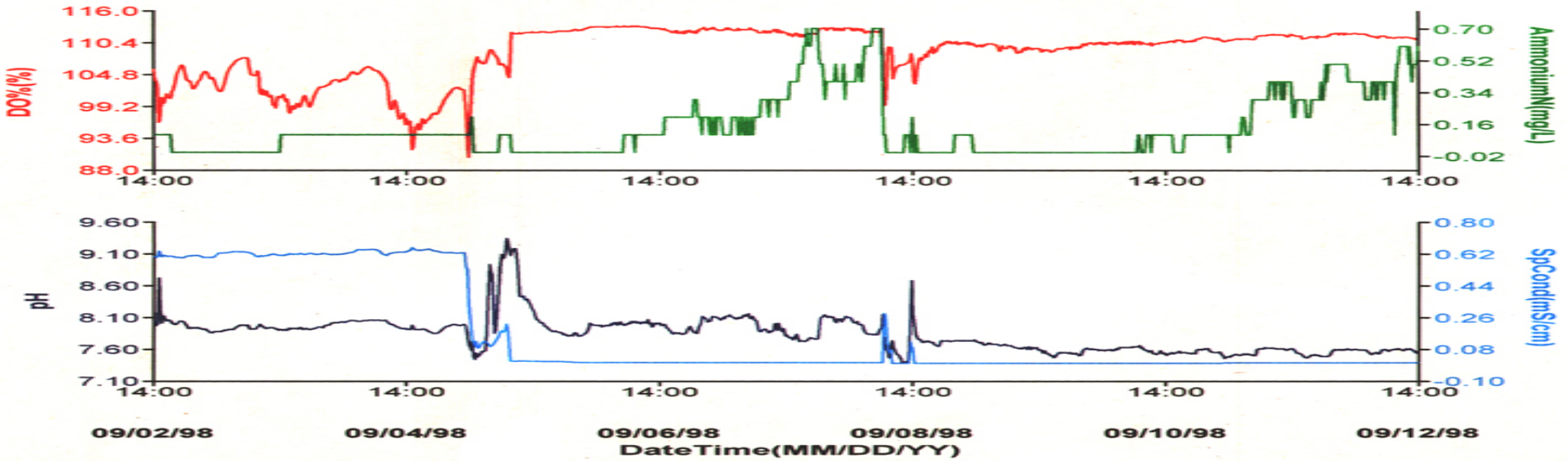
Hall Brook run 1. 2-12 September 1998
Finham Rainfall



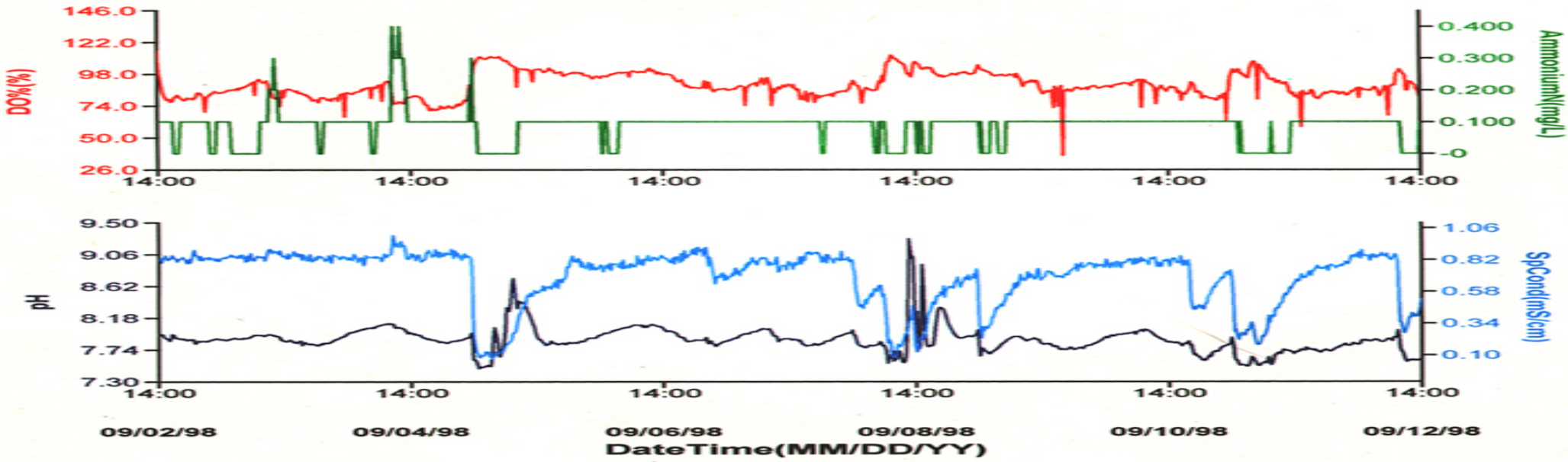
a) Hall Brook St Paul's Cemetery



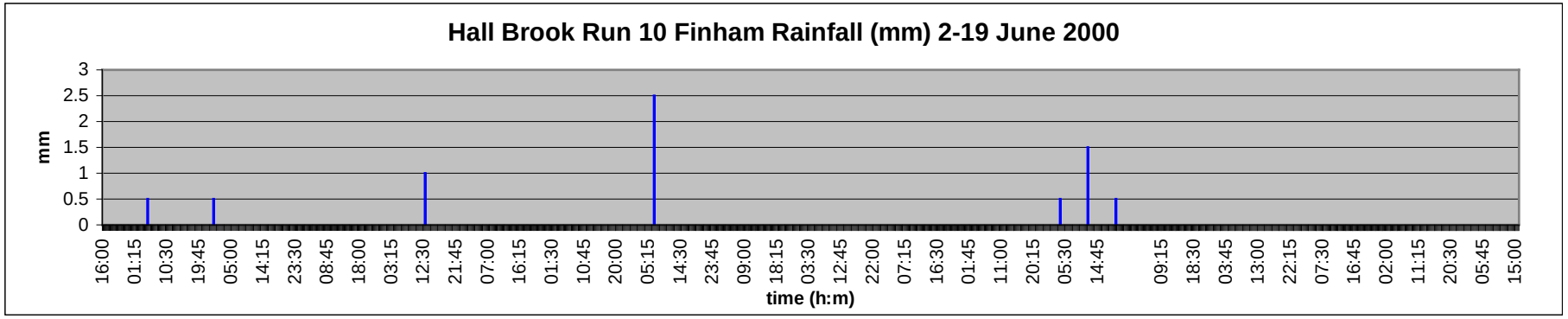
b) Hall Brook Kirkdale Avenue manhole 913



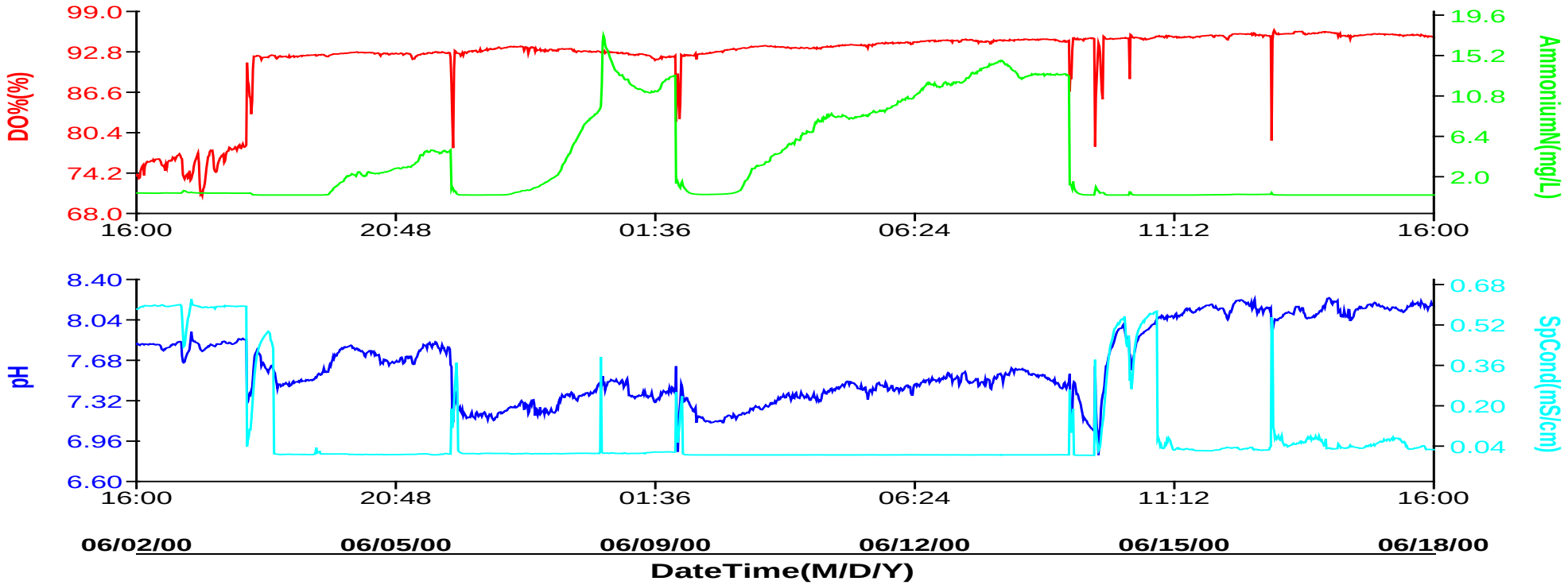
c) Hall Brook Foleshill Gasworks



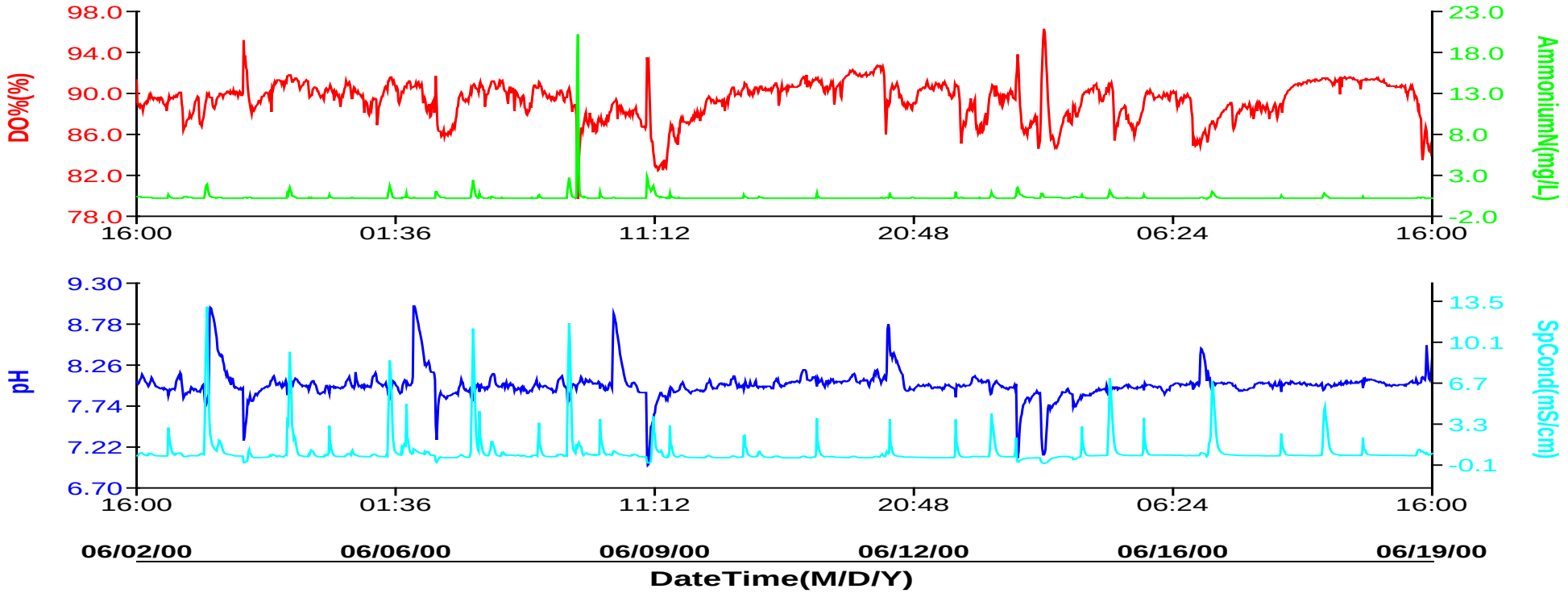
Hall Brook run 10. 2-18 June 2000
Finham Rainfall



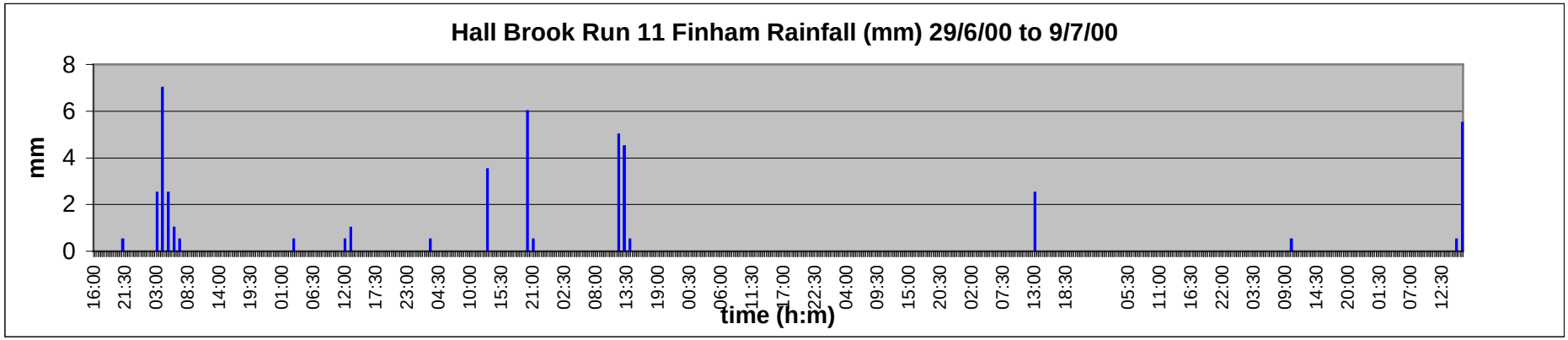
a) Hall Brook Foleshill Park Upstream of Dunlop Interceptor



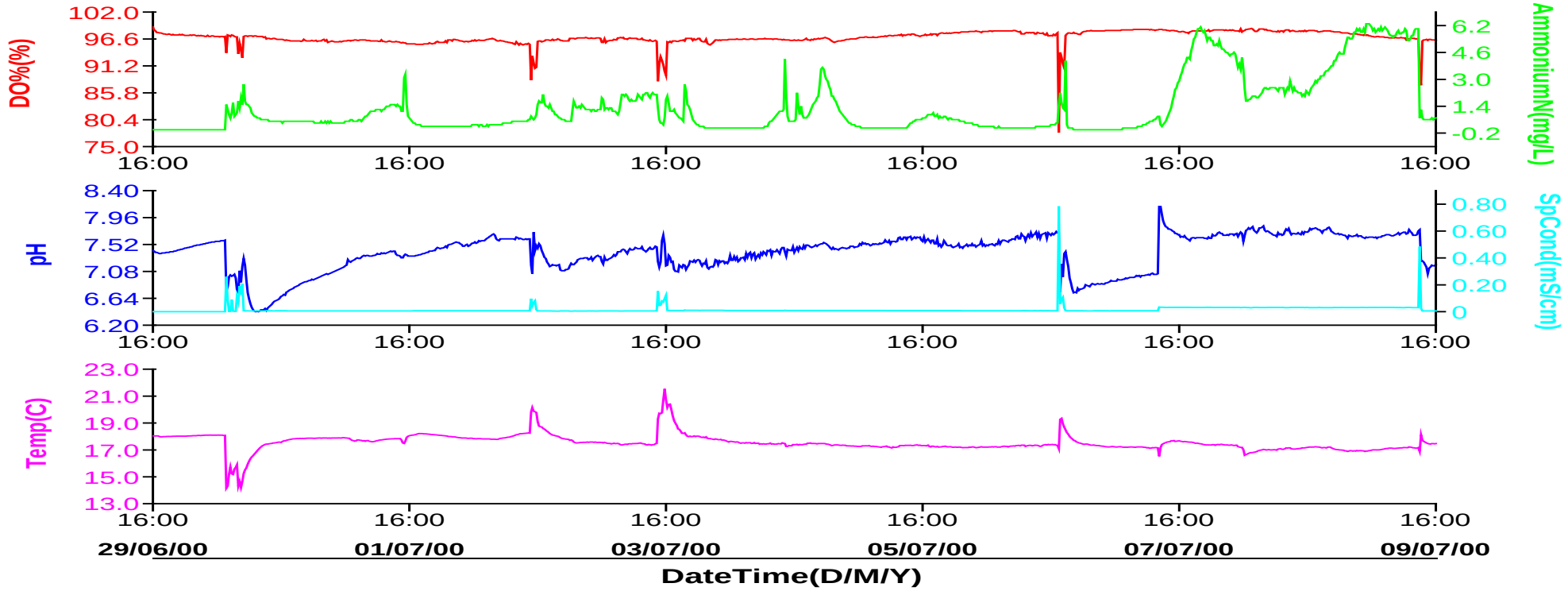
b) Hall Brook Foleshill Park Downstream of Dunlop Interceptor



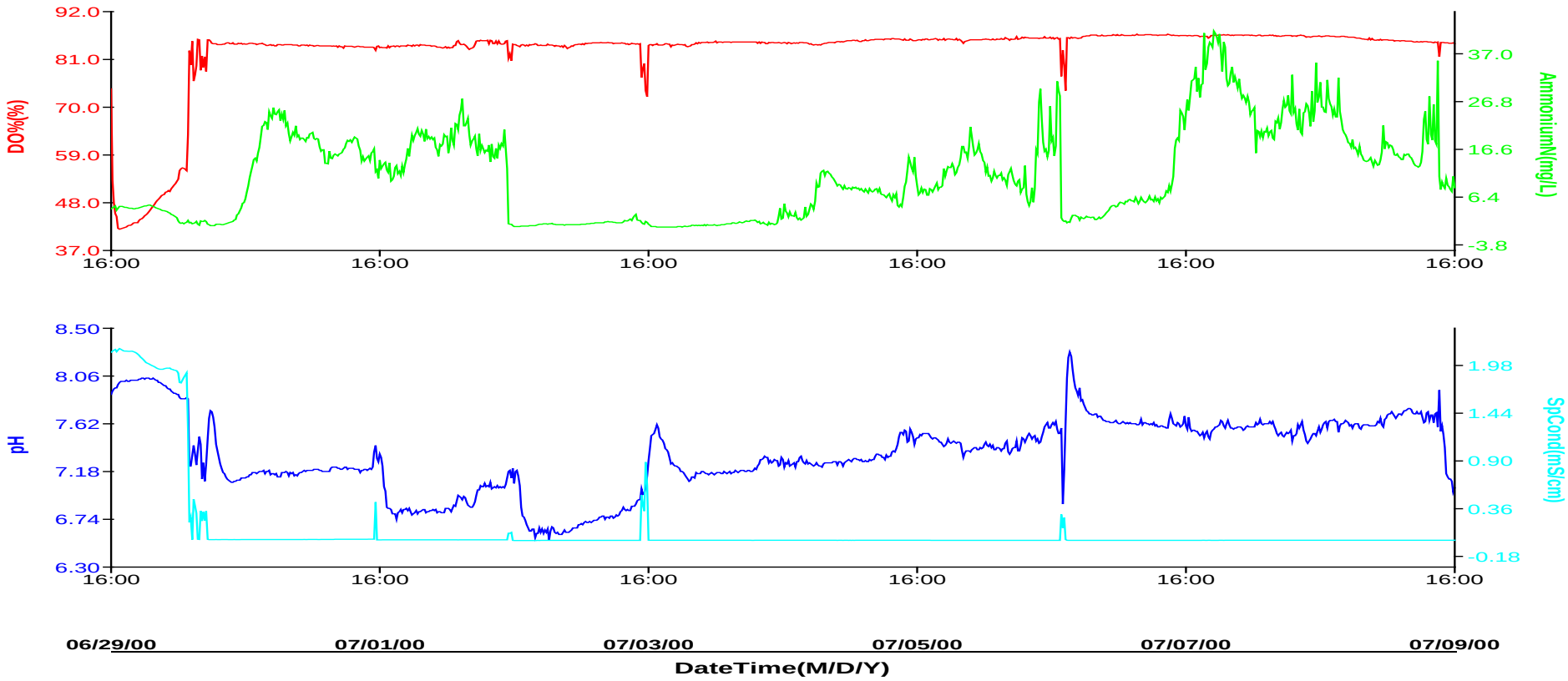
Hall Brook run 11. 29 June to 9 July 2000
Finham Rainfall



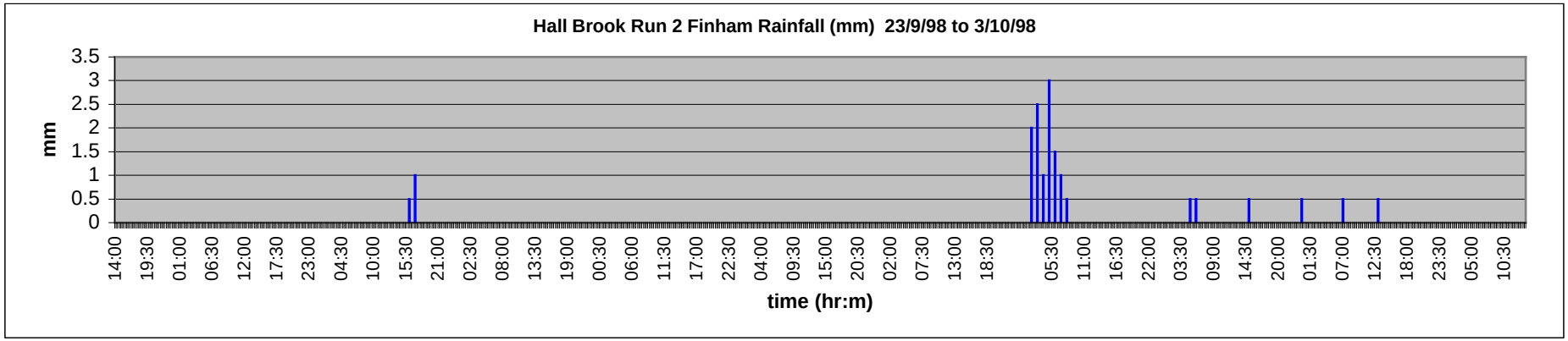
a) Hall Brook Dunlop site drainage



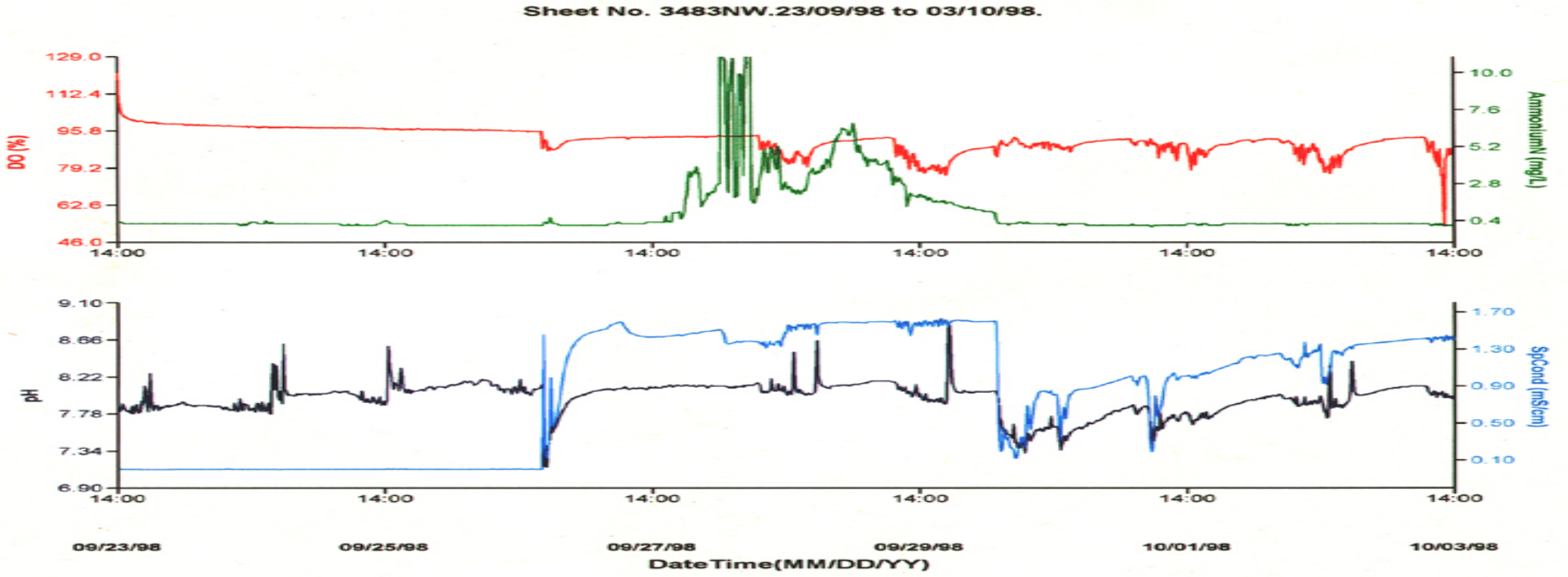
b) Hall Brook Holbrook lane manhole 534 Dunlop Arm



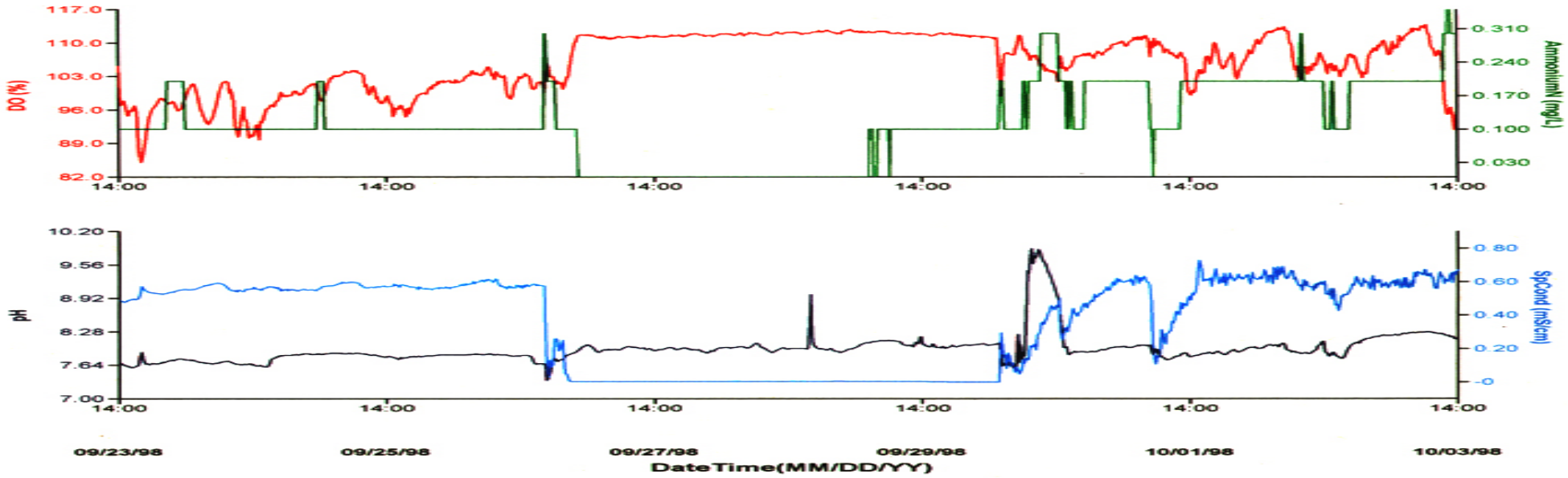
Hall Brook run 2. 23 September to 3 October 1998
Finham Rainfall



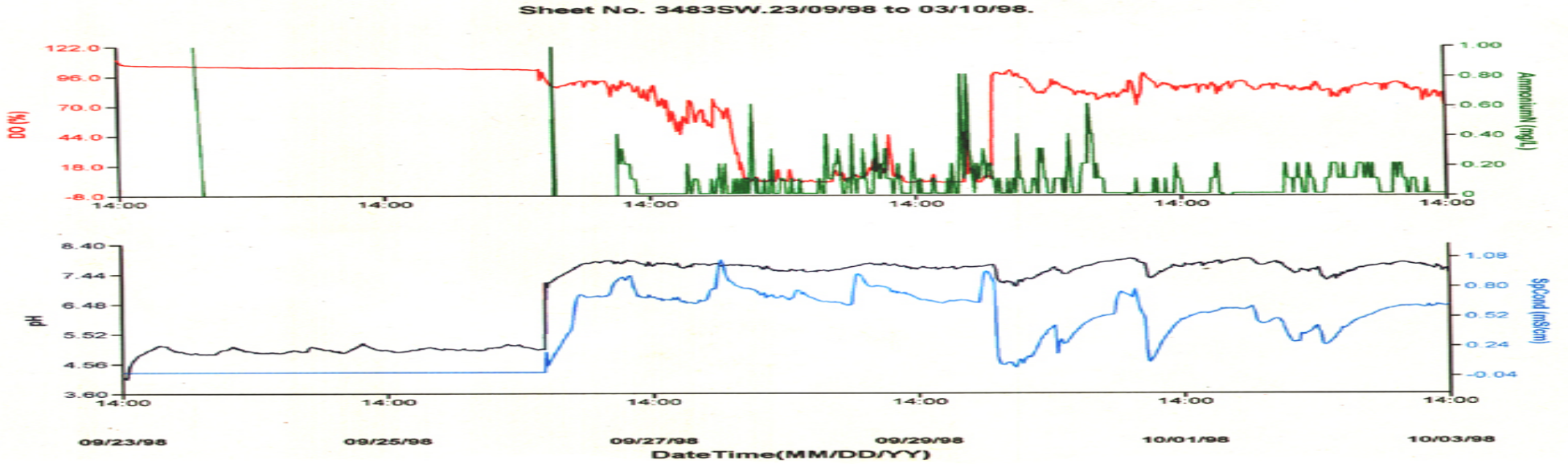
a) Hall Brook Hen Lane



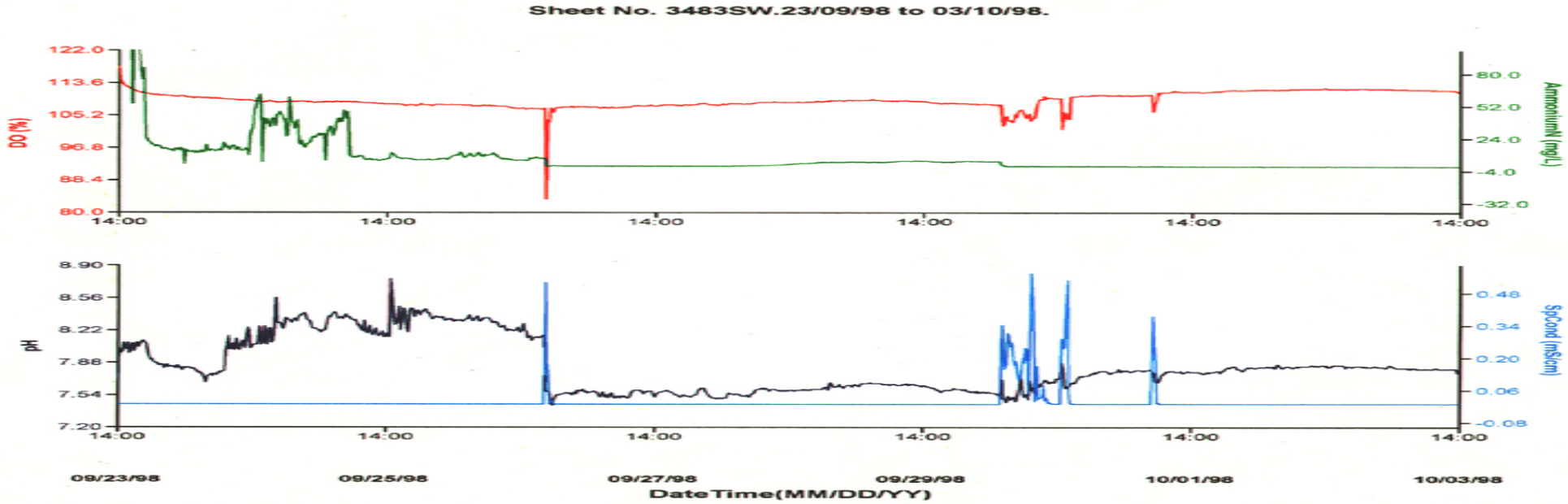
b) Hall Brook Marshdale Avenue manhole 115



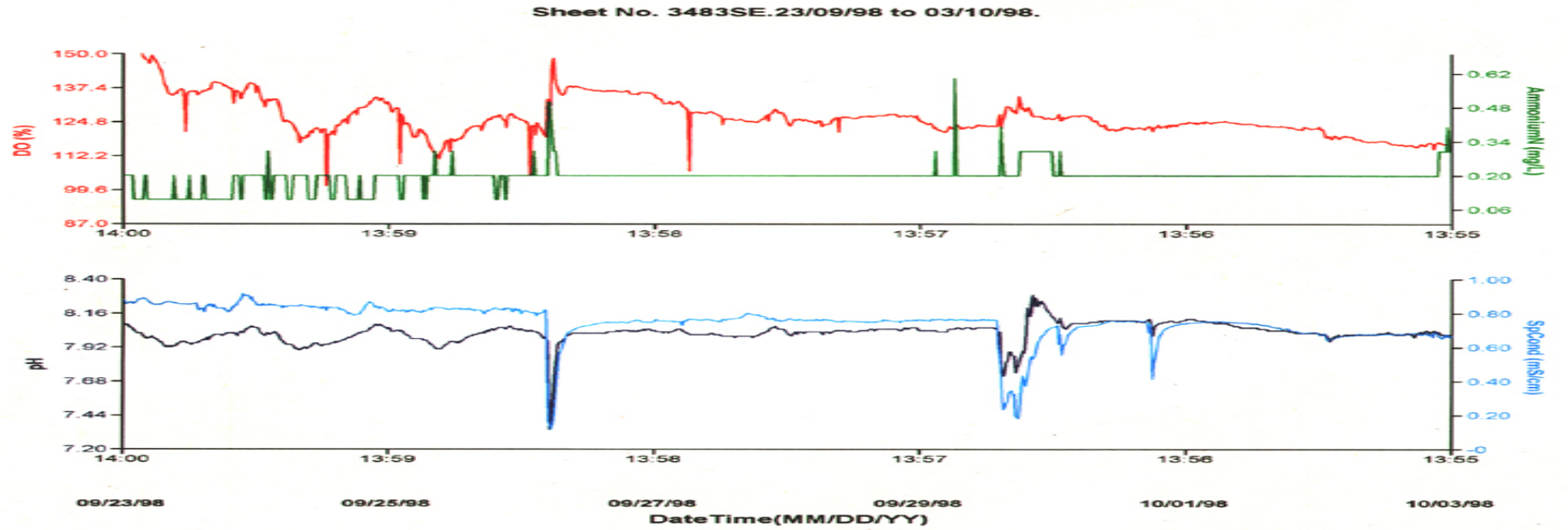
d) Hall Brook Marshdale Avenue manhole 113



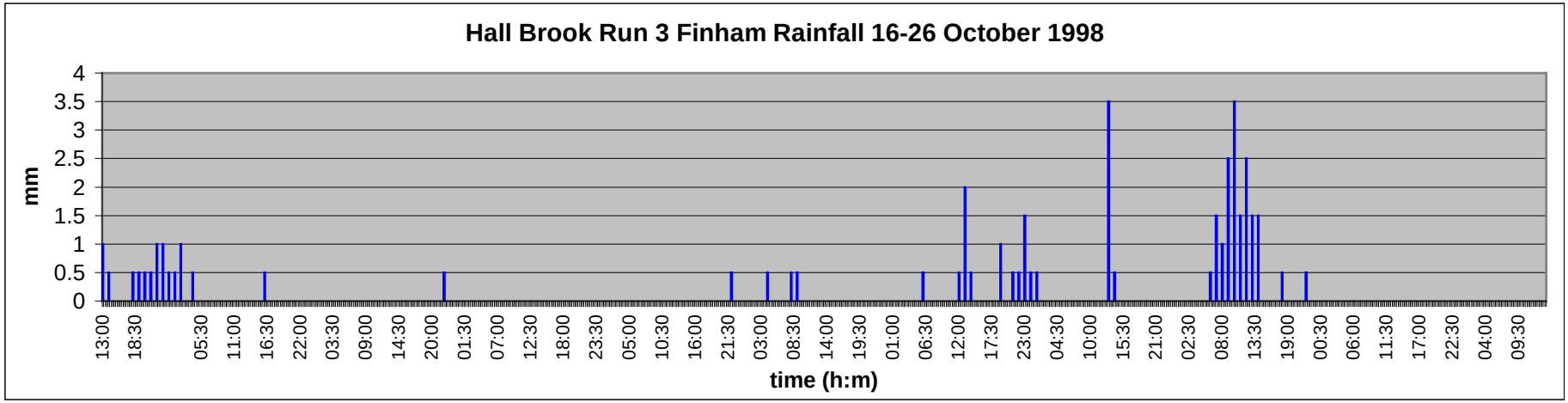
e) A444 manhole 143



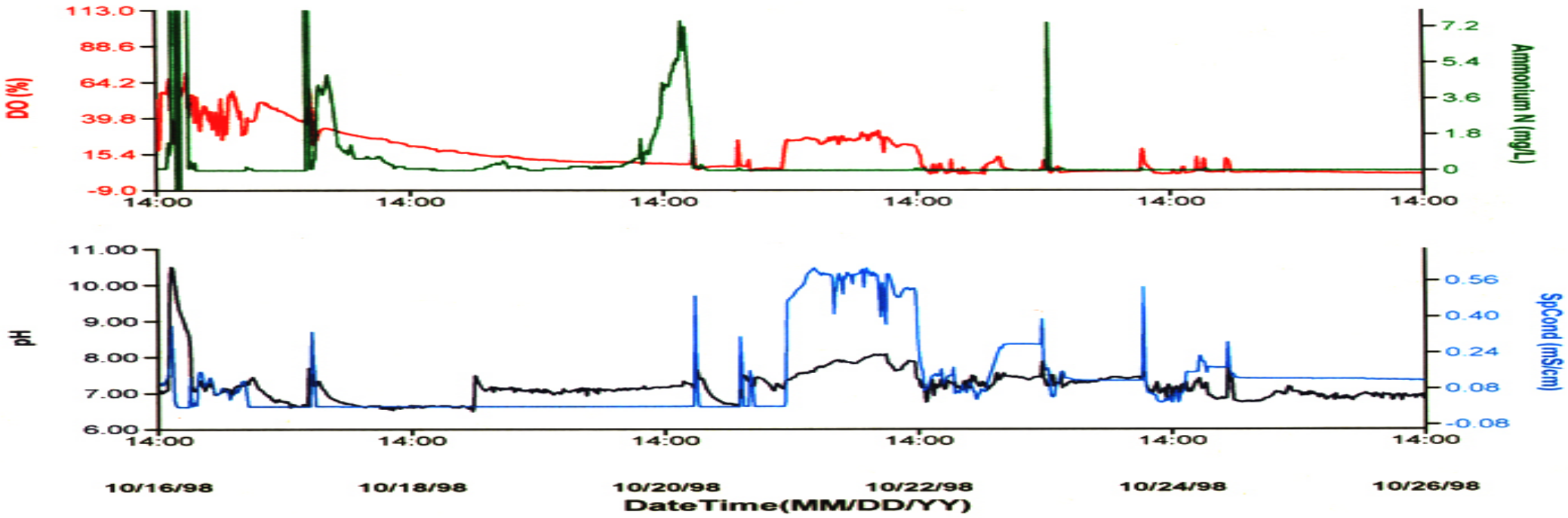
f) Hall Brook Doyle Drive



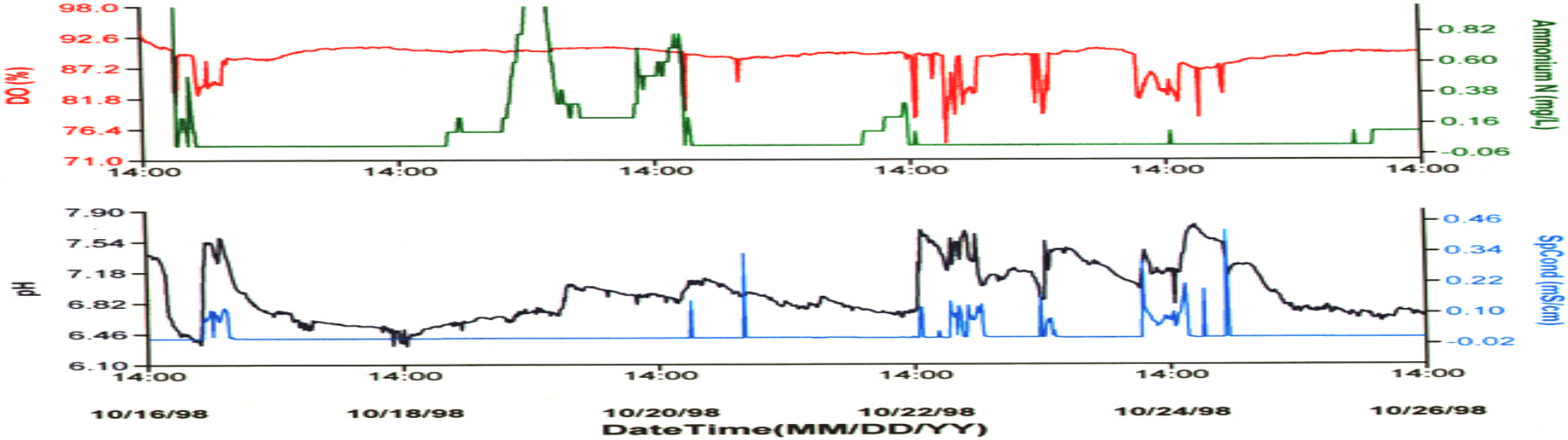
Hall Brook run 3. 16-26 October 1998
Finham Rainfall



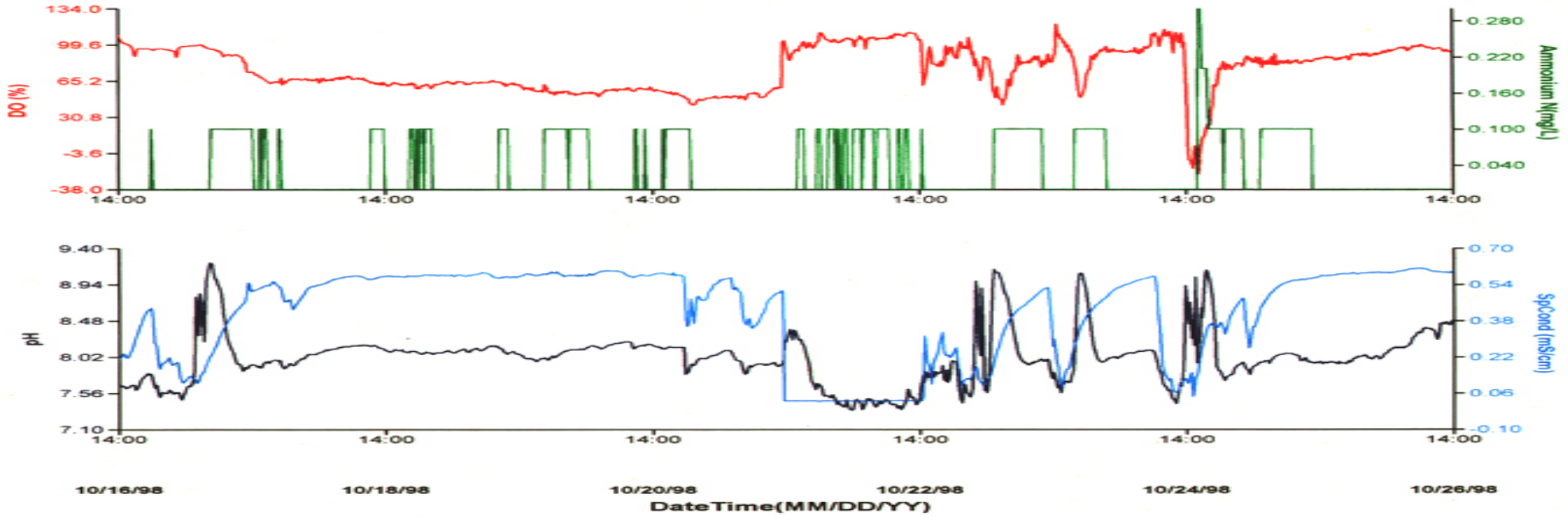
a) Hall Brook Lythalls Lane manhole 971



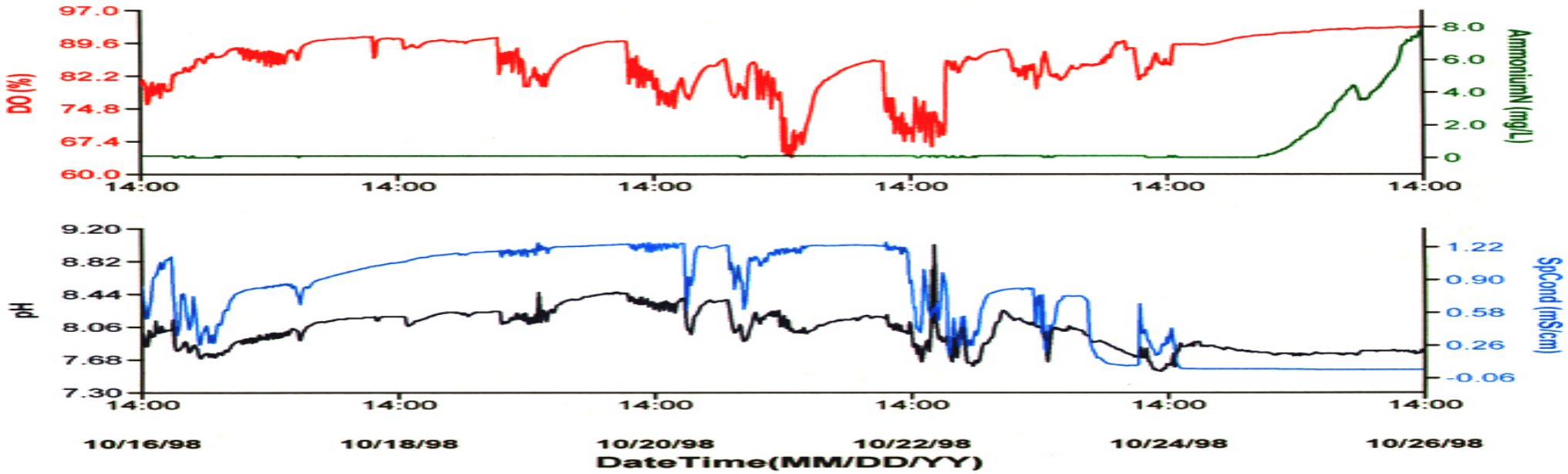
b) Hall Brook Marlissa Drive (side arm from industrial estate)



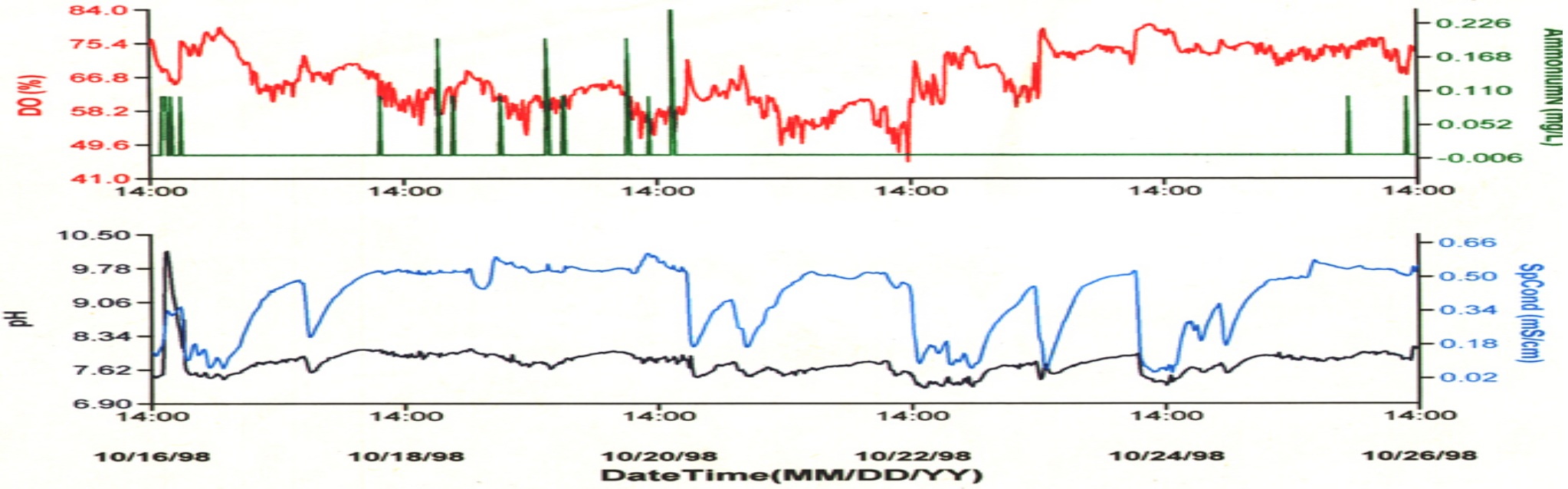
c) Hall Brook Marshdale Avenue manhole 113 (Dunlop arm)



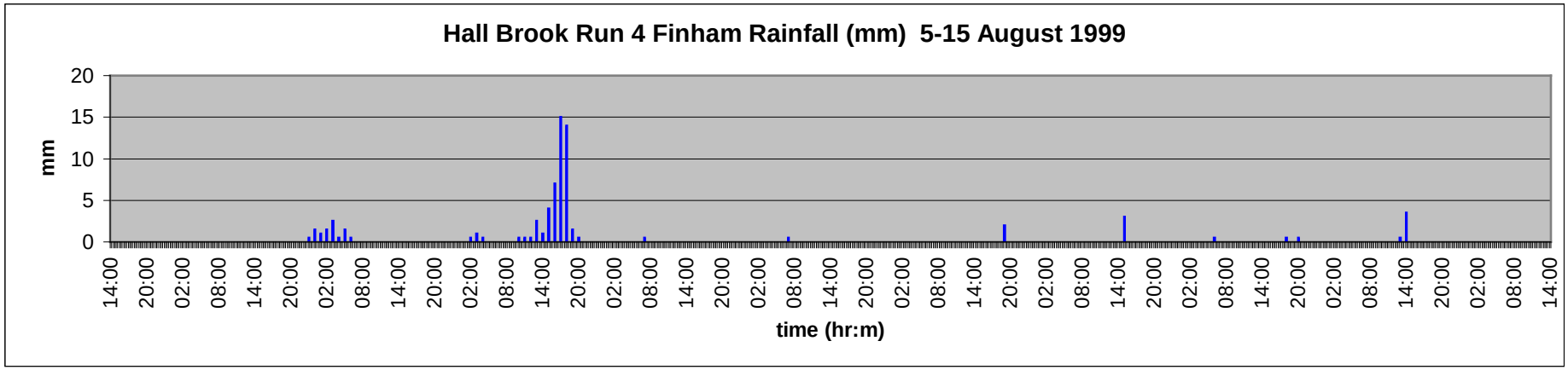
d) Hall Brook Hen lane manhole 052



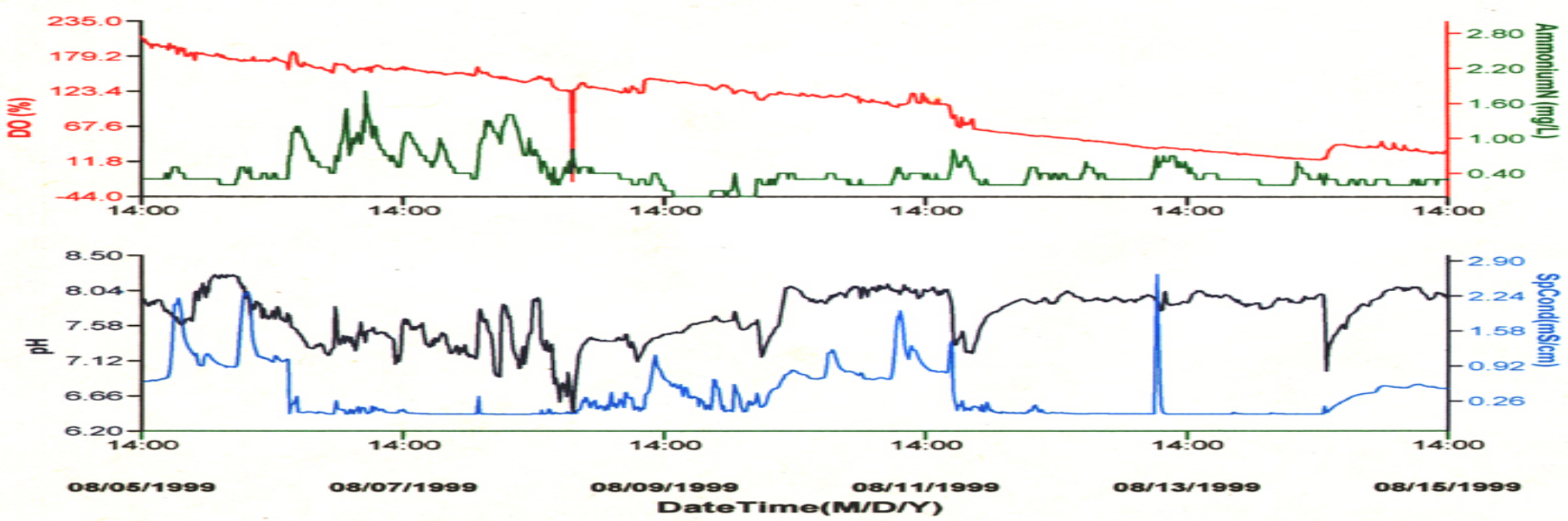
e) Hall Brook Marshdale Avenue manhole 115 Colliery sidings



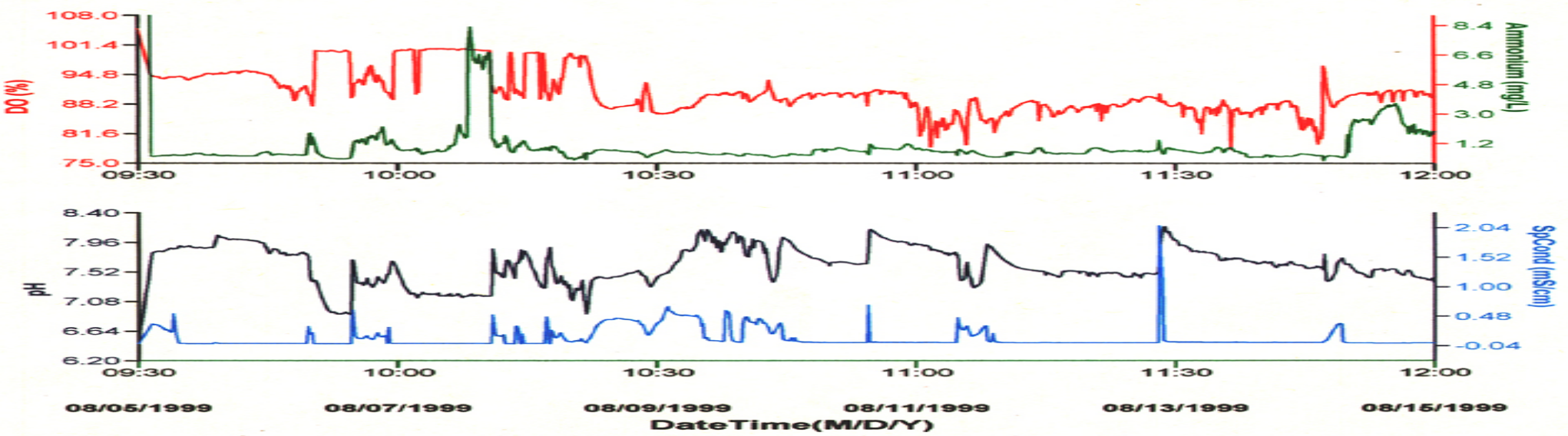
Hall Brook run 4. 5-15 August 1999
Finham Rainfall



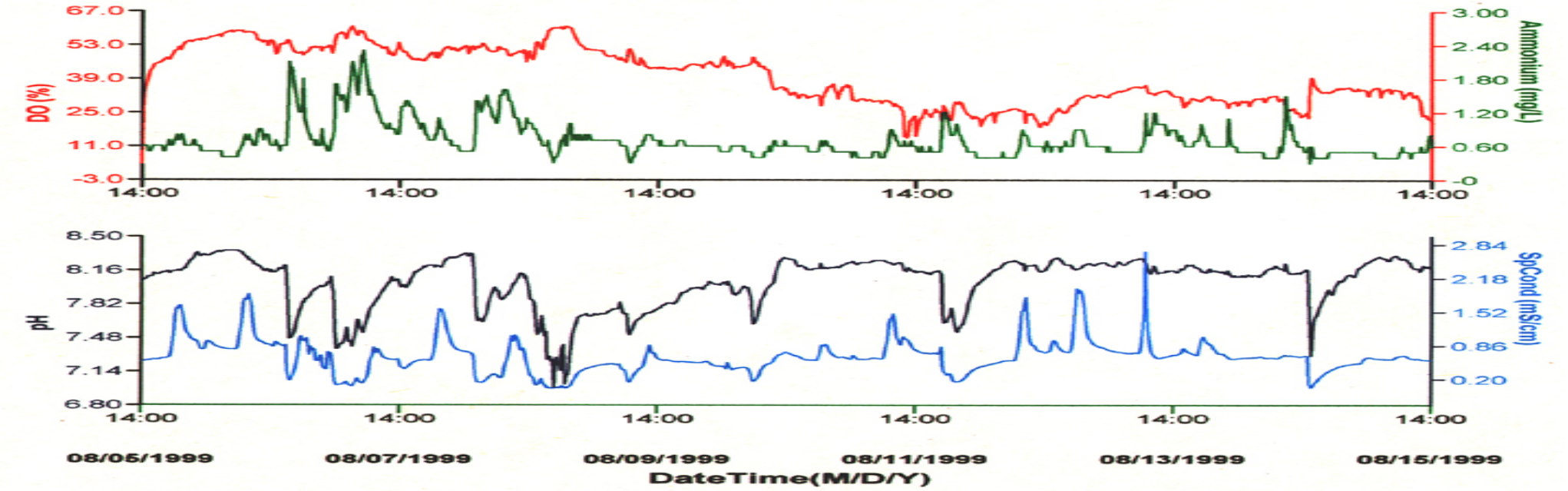
a) Hall Brook Lythalls Lane manhole 971



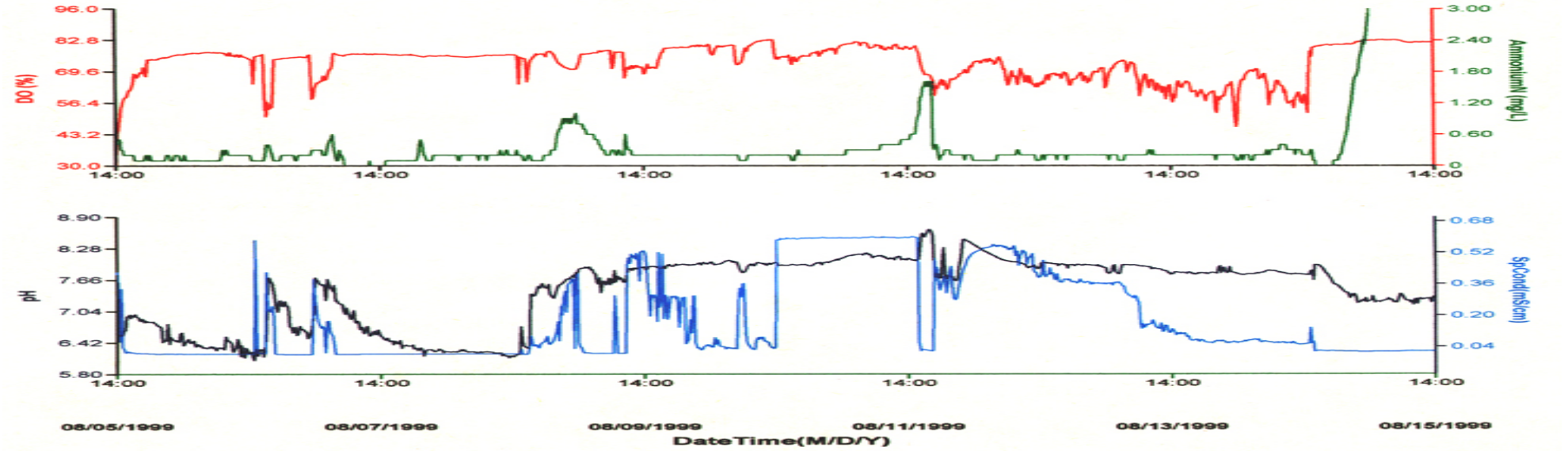
b) Hall Brook Marlissa Drive Surface Water sewer outfall



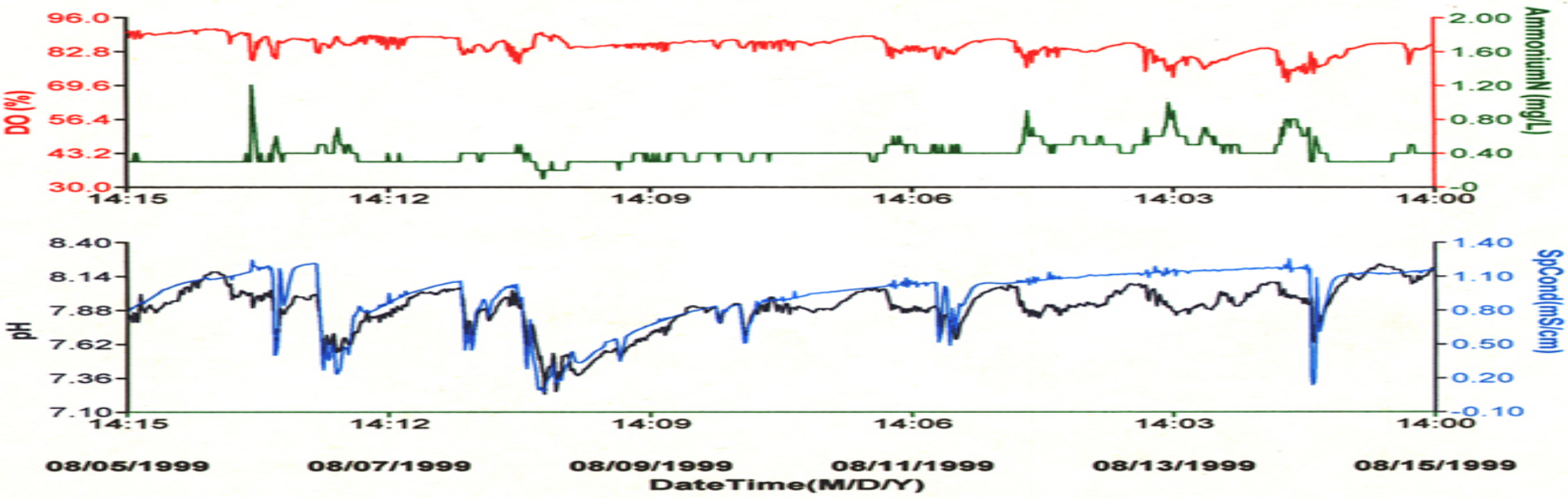
c) Marshdale Avenue Dunlop arm manhole 113



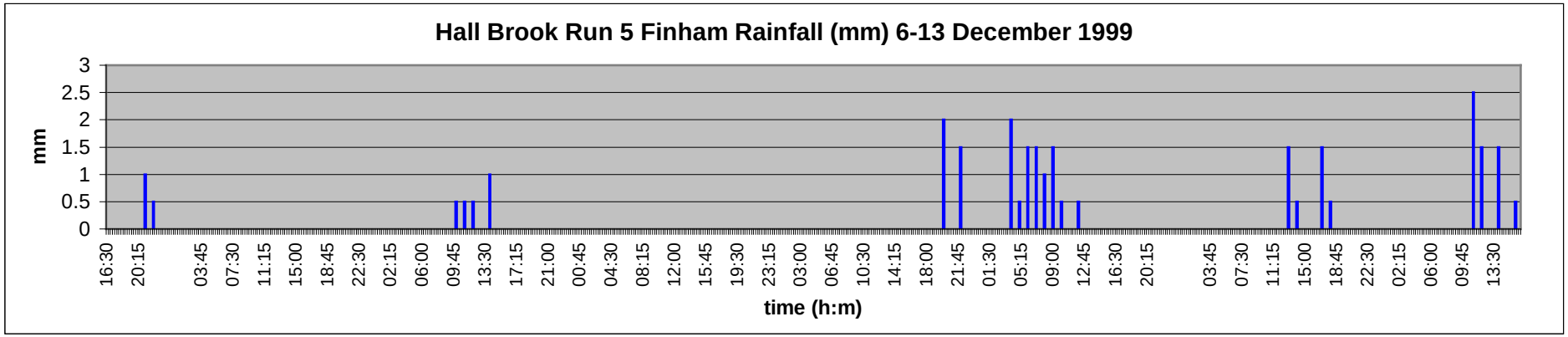
d) Hall Brook Hen Lane



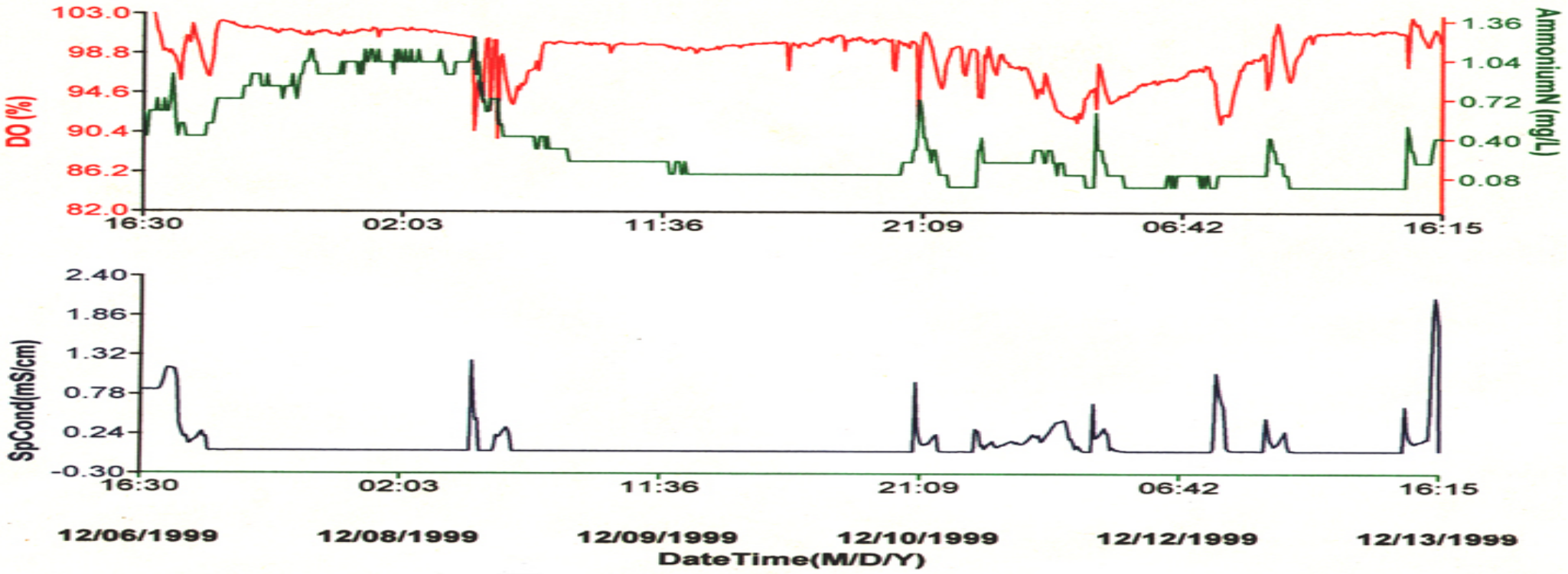
e) Hall Brook Marshdale Avenue manhole 114



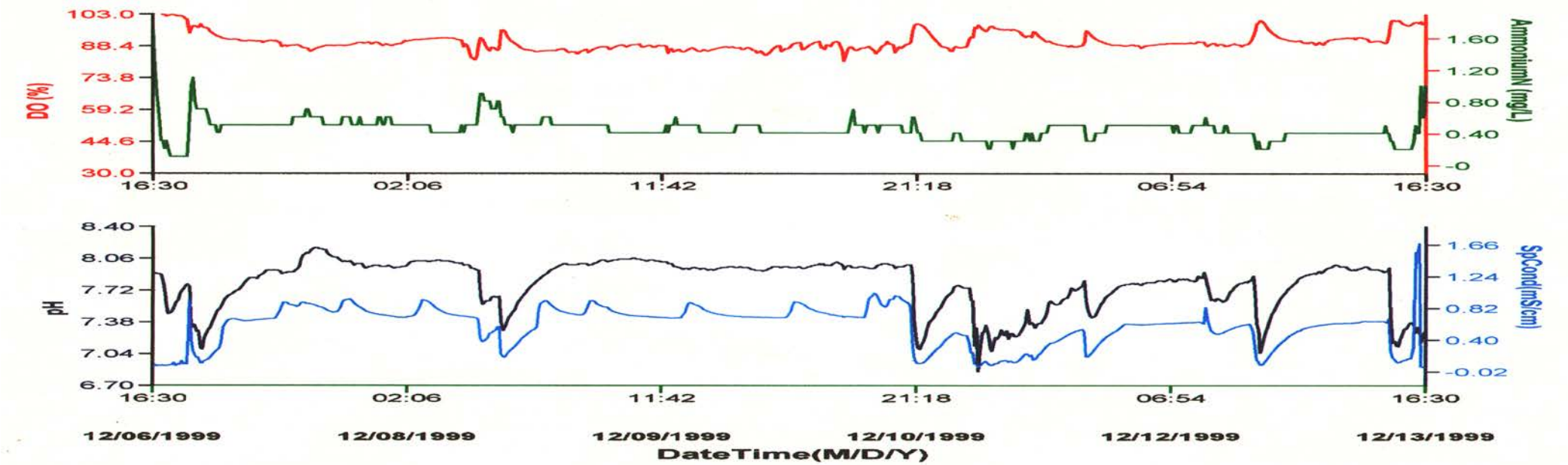
Hall Brook run 5. 6-12 December 1999
Finham Rainfall



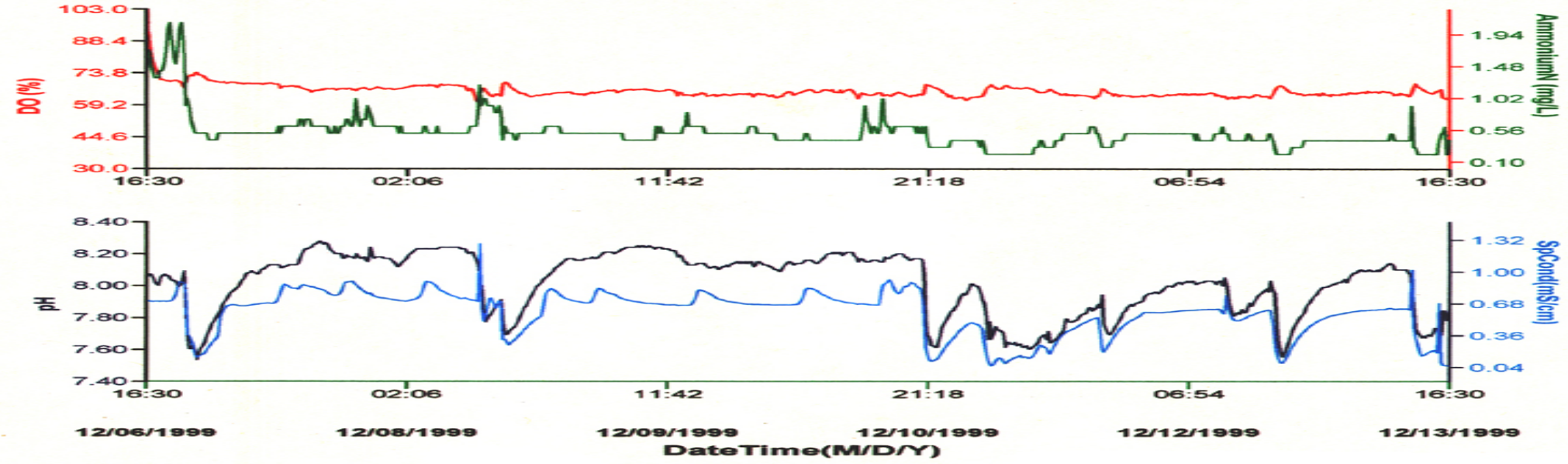
a) Hall Brook St Paul's Cemetery



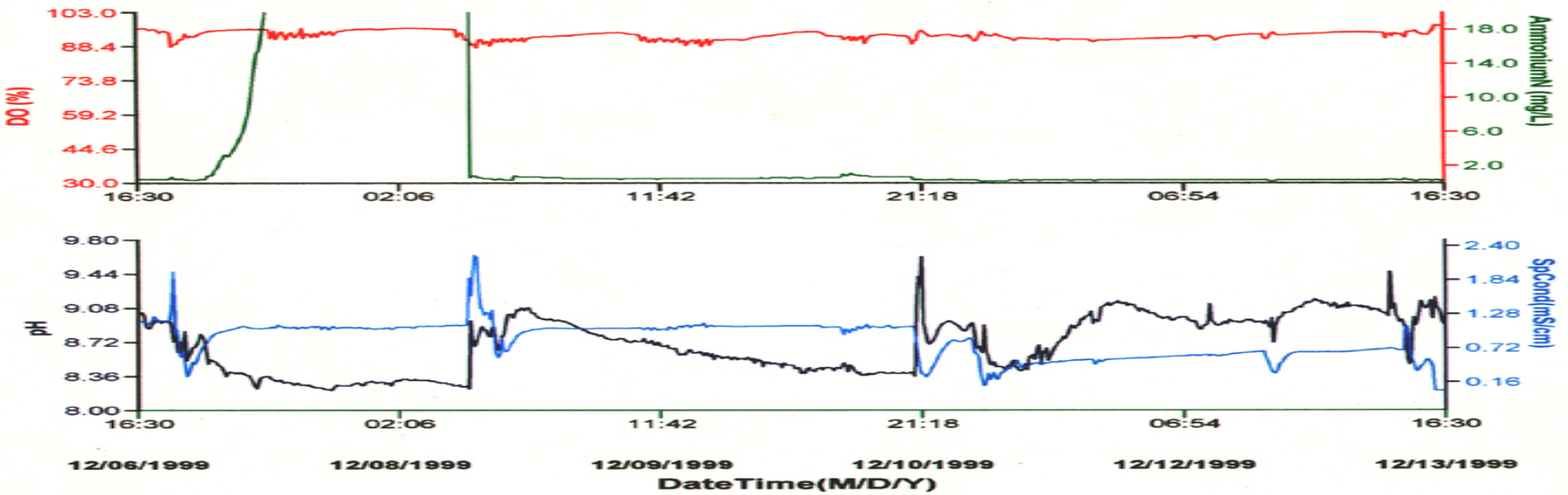
b) Hall Brook Lythalls Lane manhole 971



c) Hall Brook Marshdale Avenue Dunlop Arm

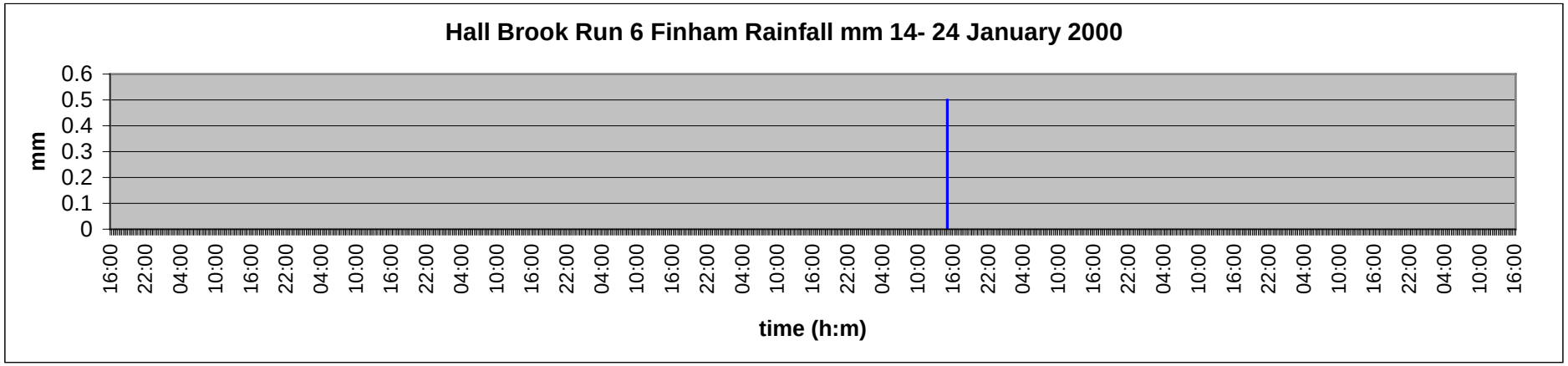


d) Hall Brook Hen Lane

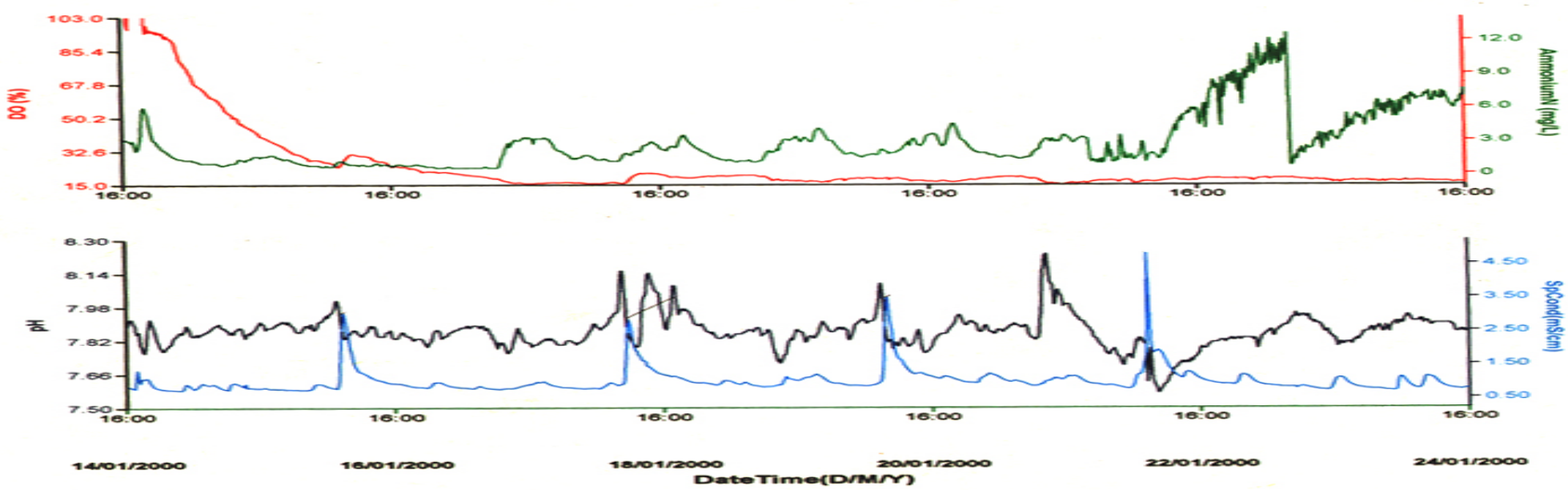


d) Hall Brook Marshdale Avenue Parkgate Arm

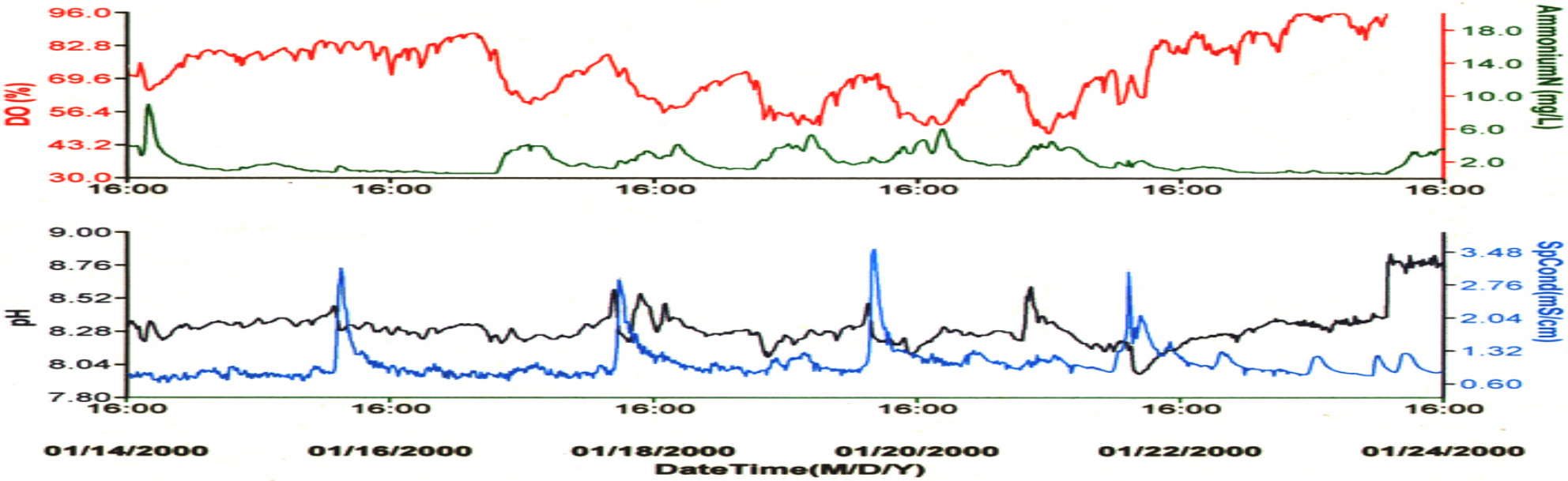
Hall Brook run 6. 14-21 January 2000
Finham Rainfall



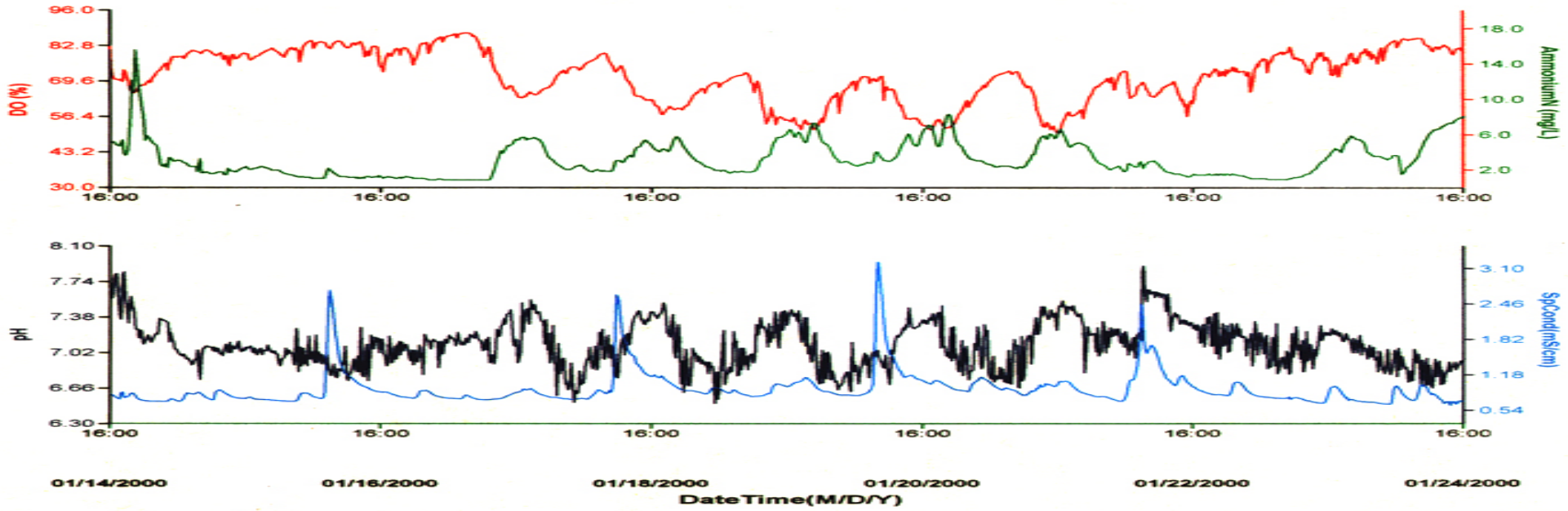
a) Hall Brook Lythalls Lane manhole 973



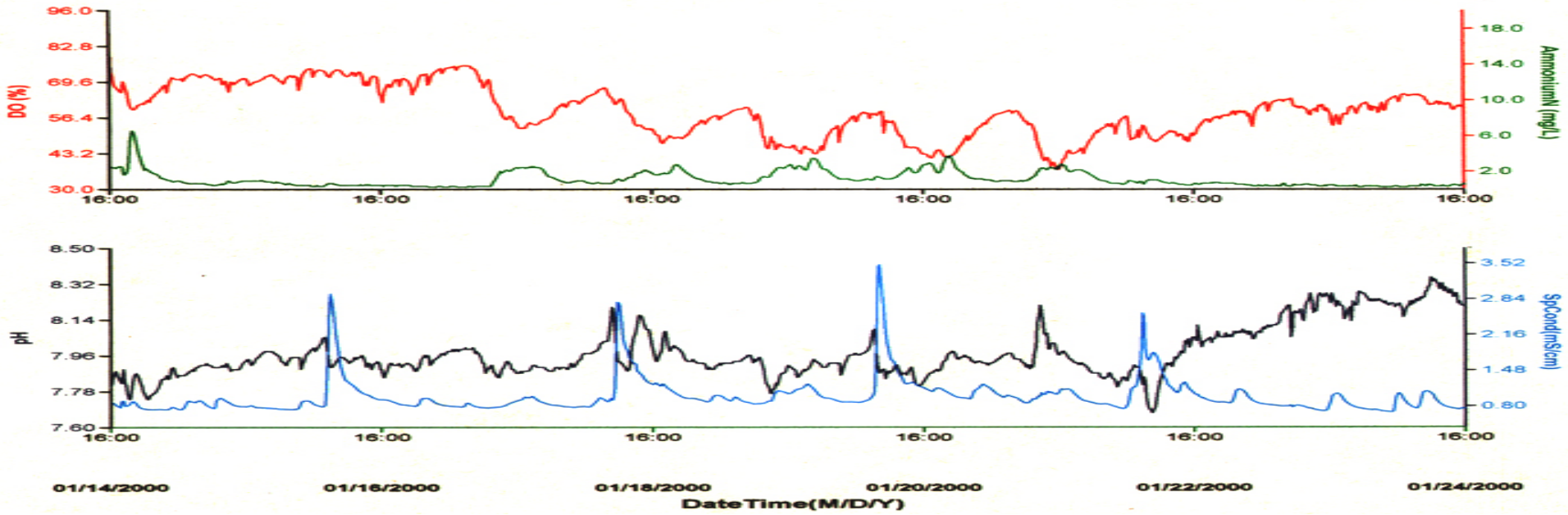
b) Hall Brook Allied Close manhole 082



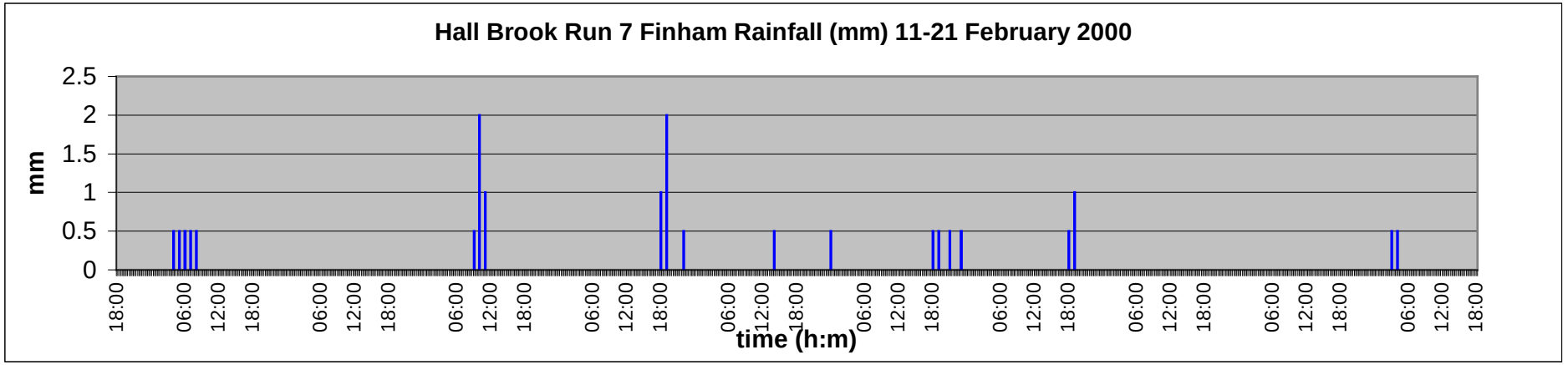
c) Hall Brook Stadium Close Gattic cover



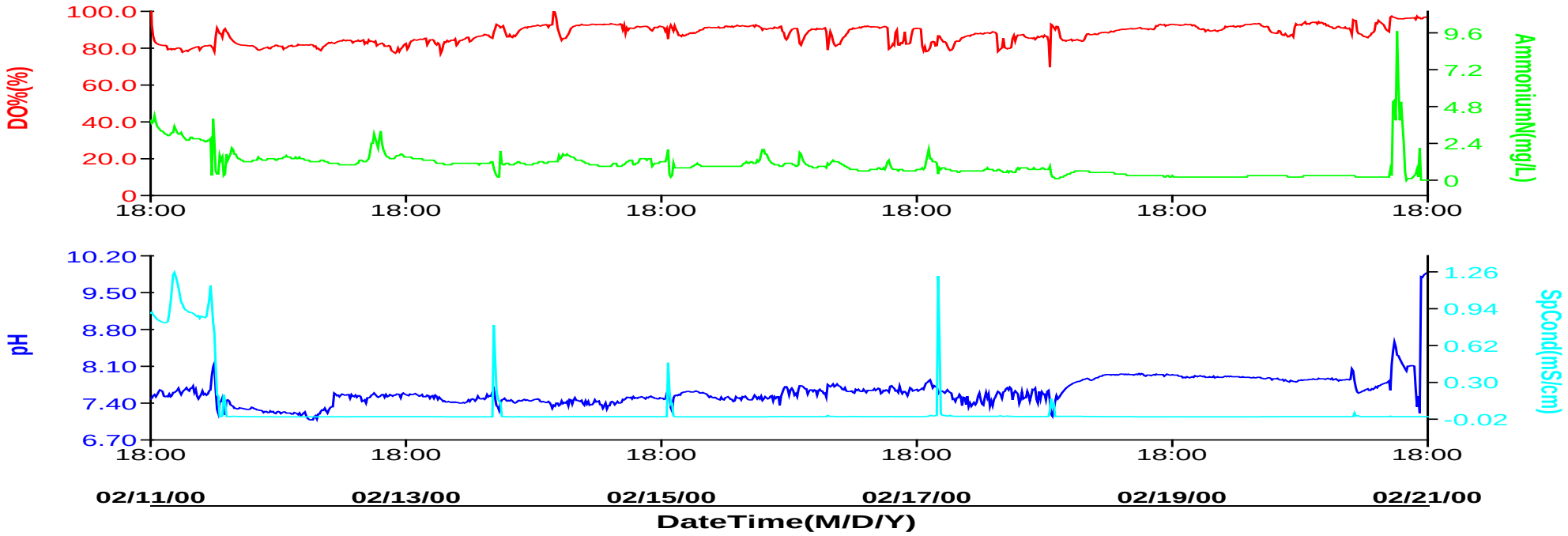
d) Hall Brook Dunster Place Gattic cover



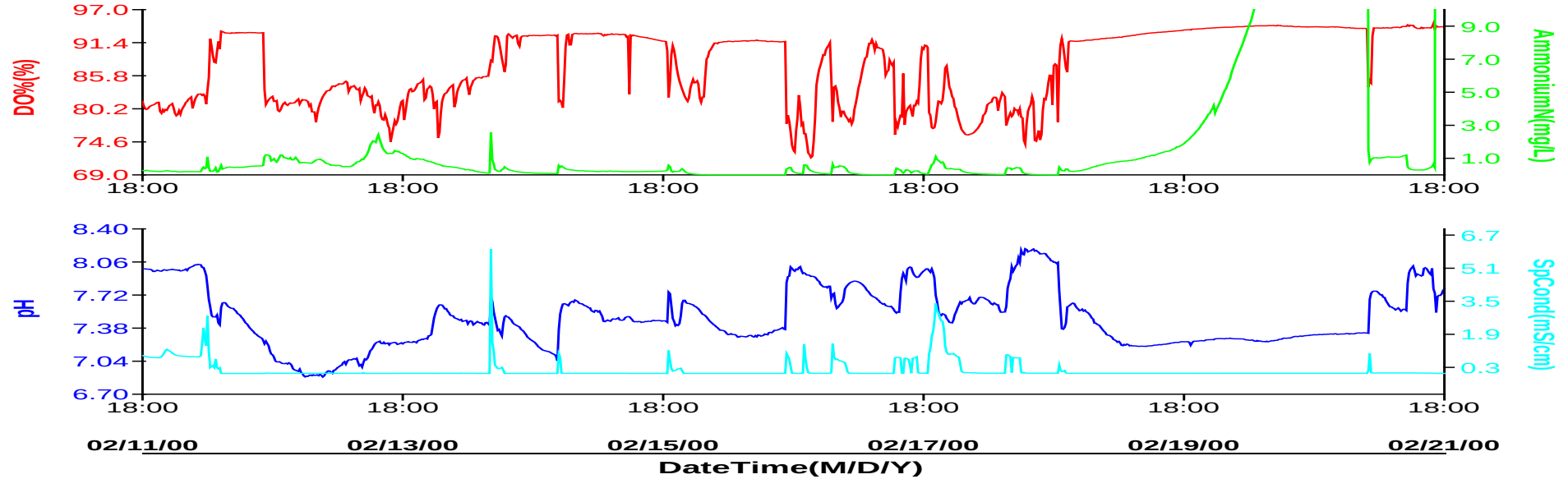
Hall Brook run 7. 11-21 February 2000
Finham Rainfall



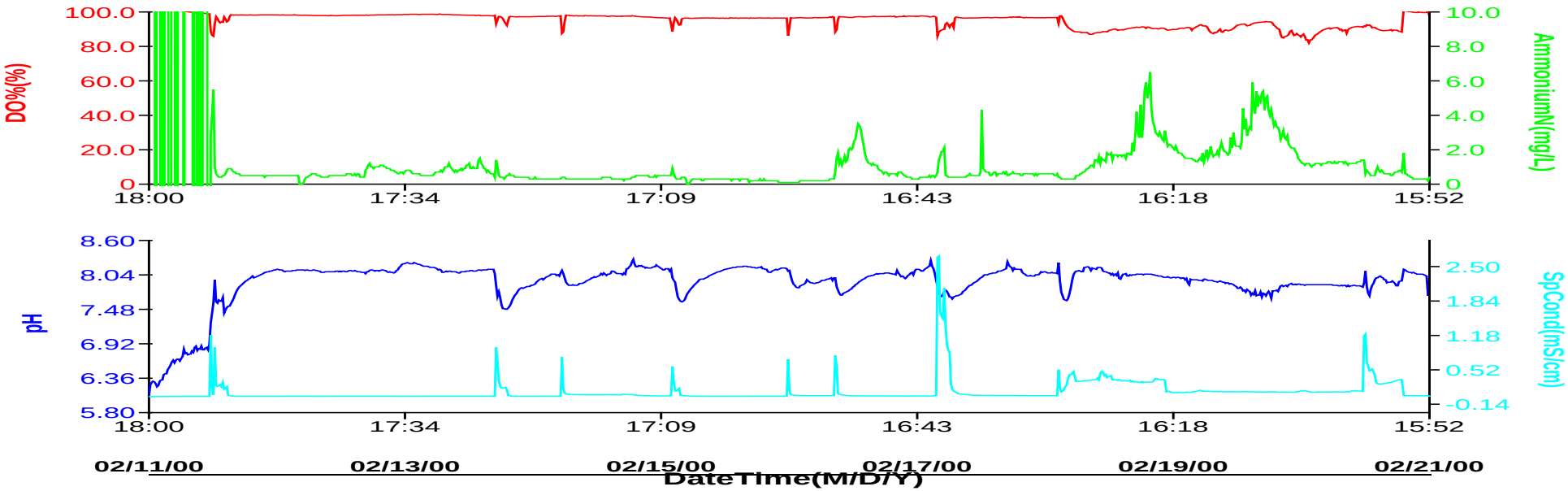
a) Hall Brook Lythalls Lane manhole 971



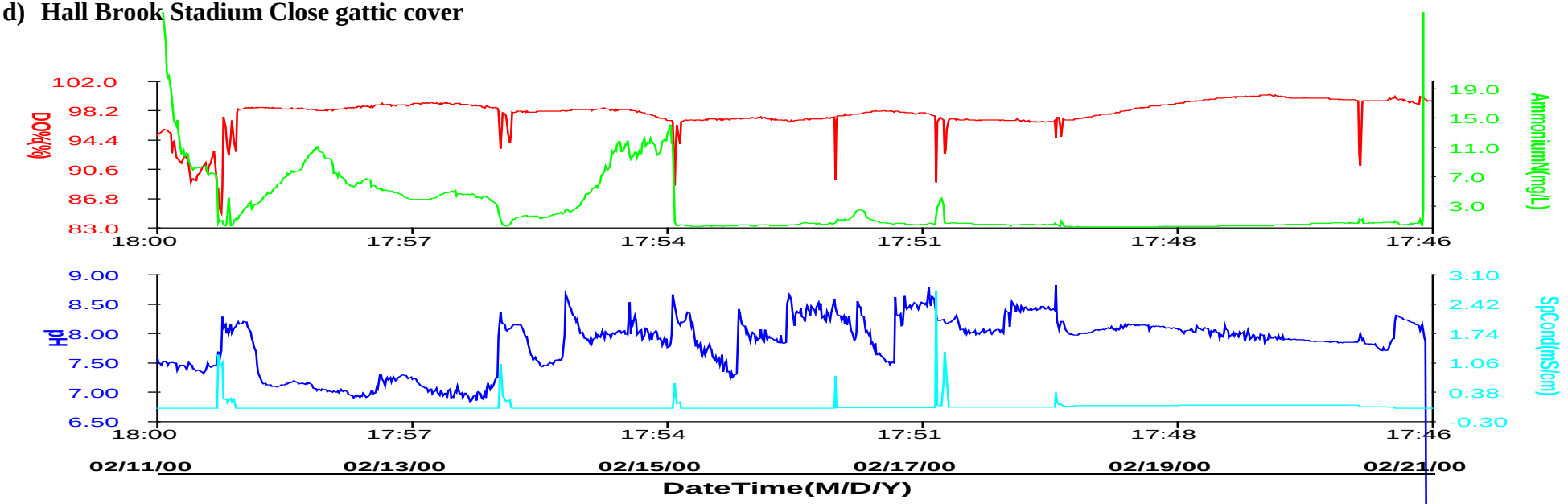
b) Hall brook Lythalls Lane manhole 974



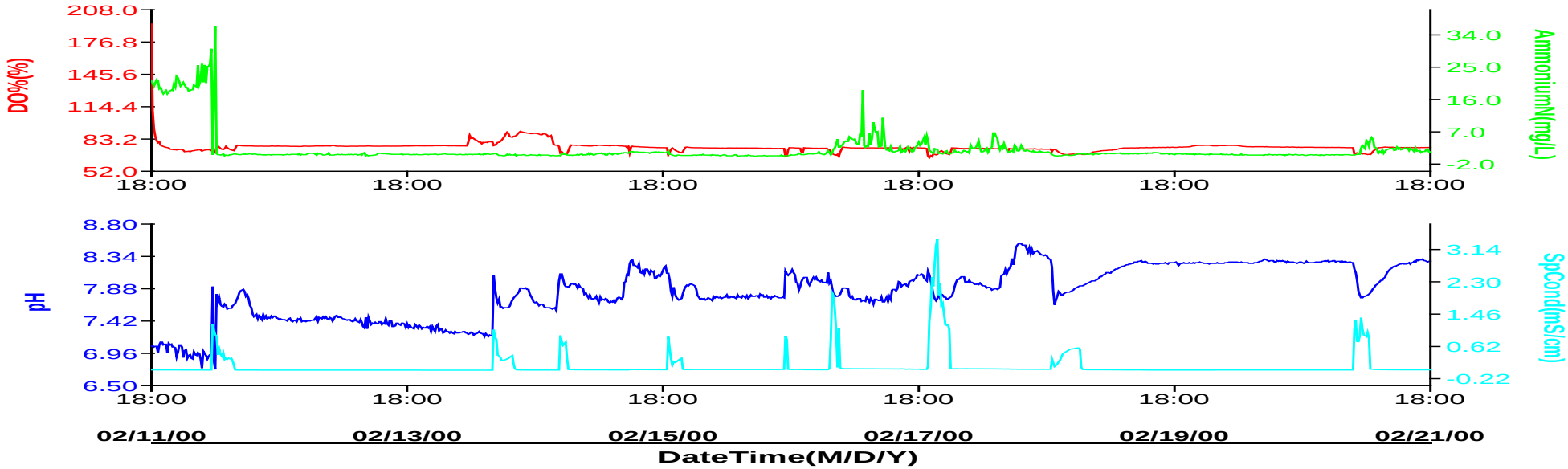
c) Hall Brook Allied Close gattic cover manhole 082



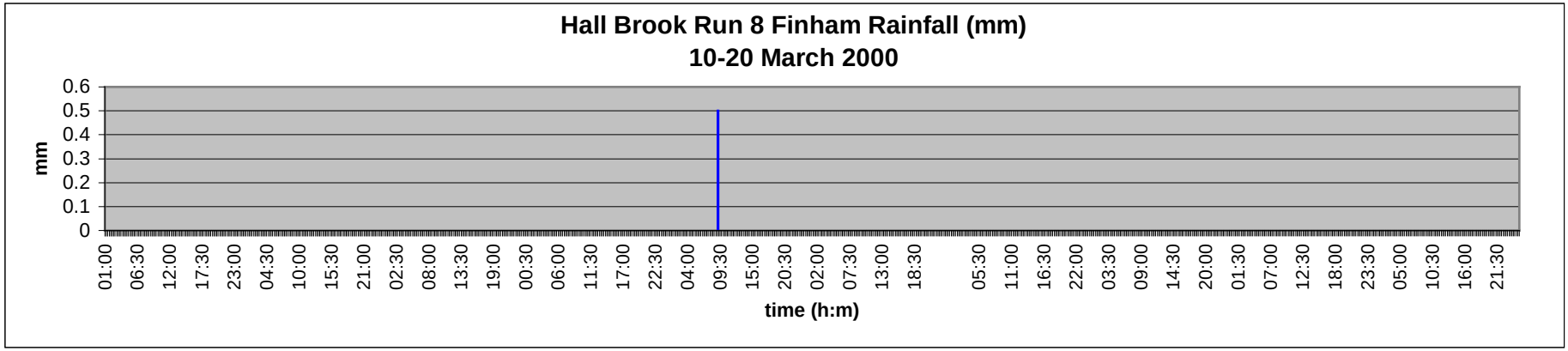
d) Hall Brook Stadium Close gattic cover



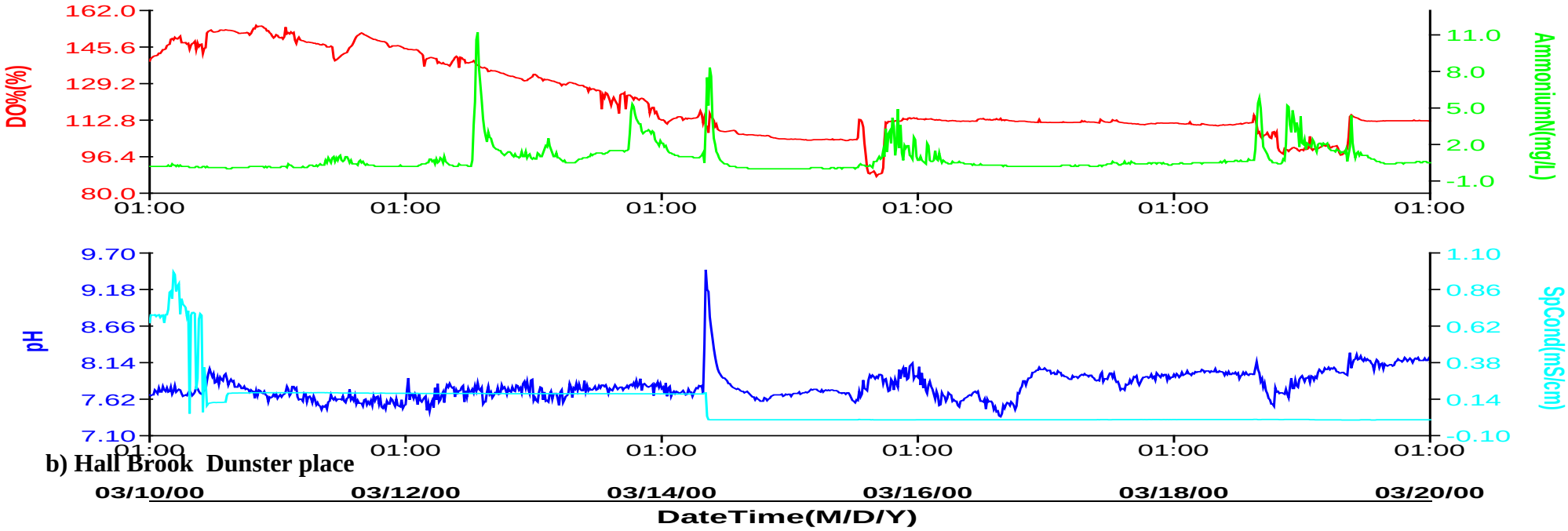
e) Hall Brook Dunster place



Hall Brook run 8. 10-20 March 2000
Finham Rainfall

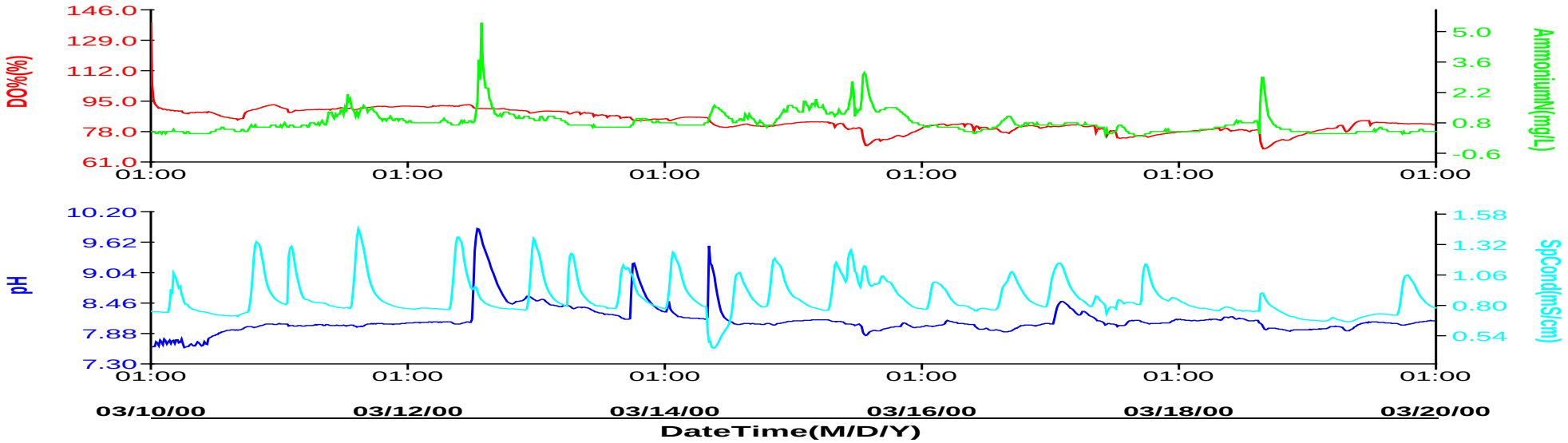


a) Hall Brook St Paul's Cemetery

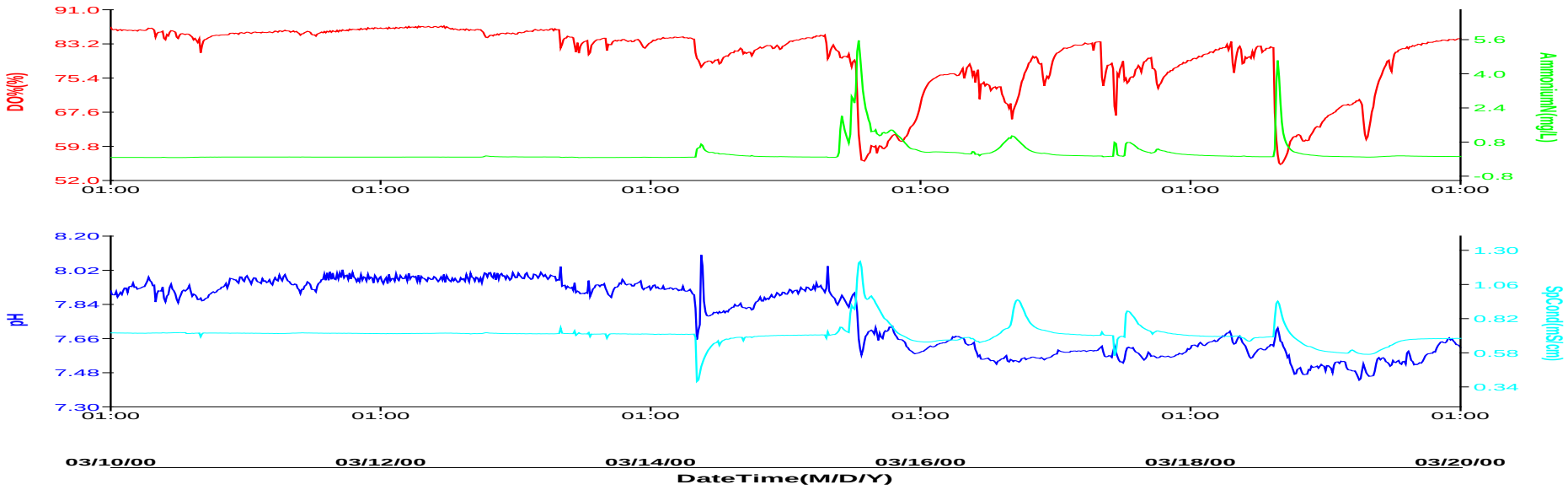


b) Hall Brook Dunster place

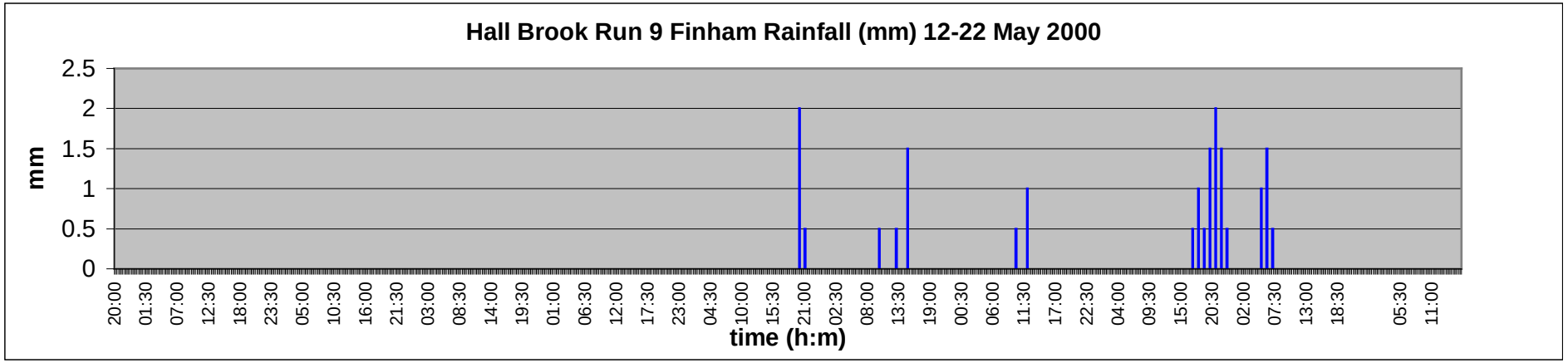
b) Hall brook Holbrook Lane manhole 544



c) Hall Brook Lane manhole 534 Dunlop Arm

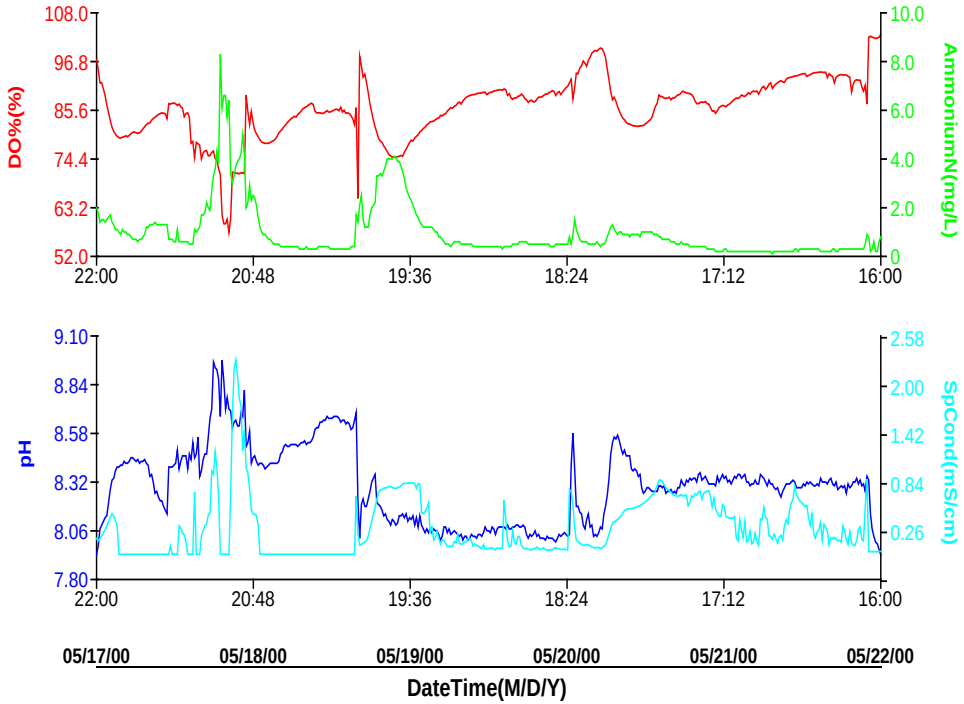


Hall Brook run 9. 12-22 May 2000
Finham Rainfall

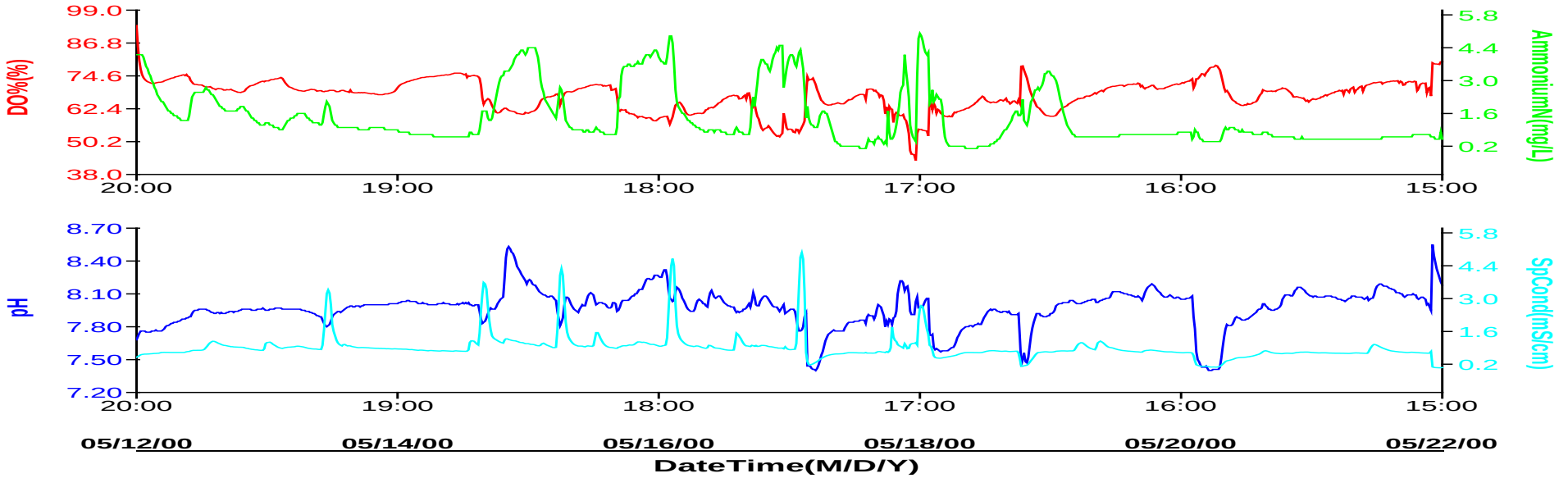


a) Hall Brook St Paul's Cemetery

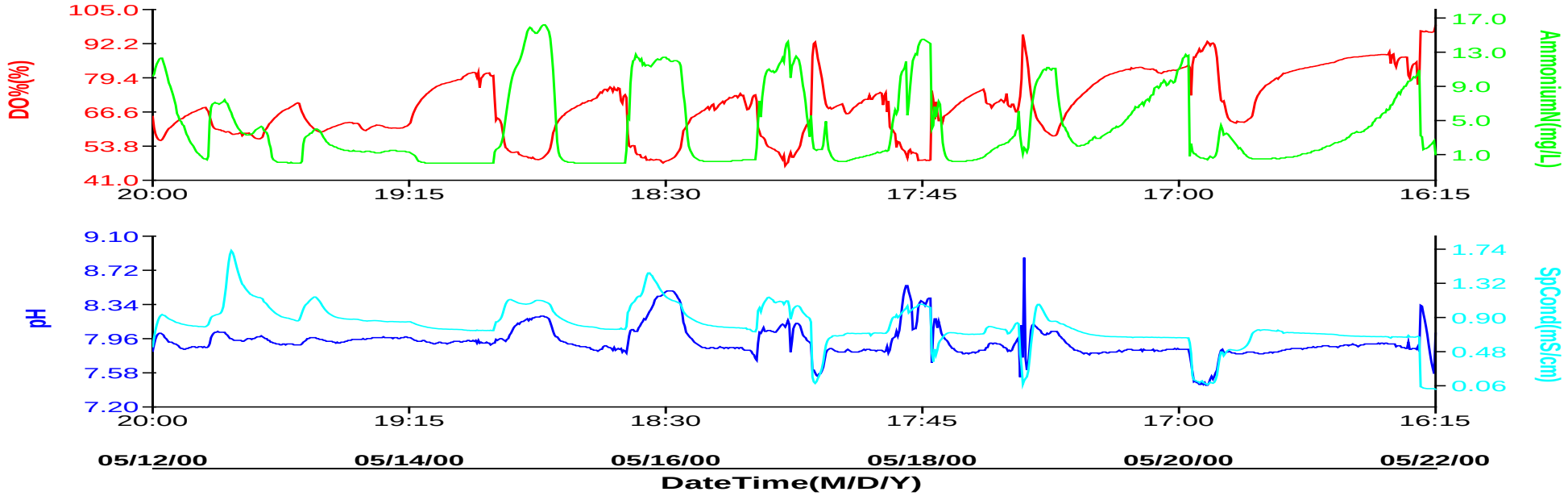
Data period for this site is 17 – 22 May only



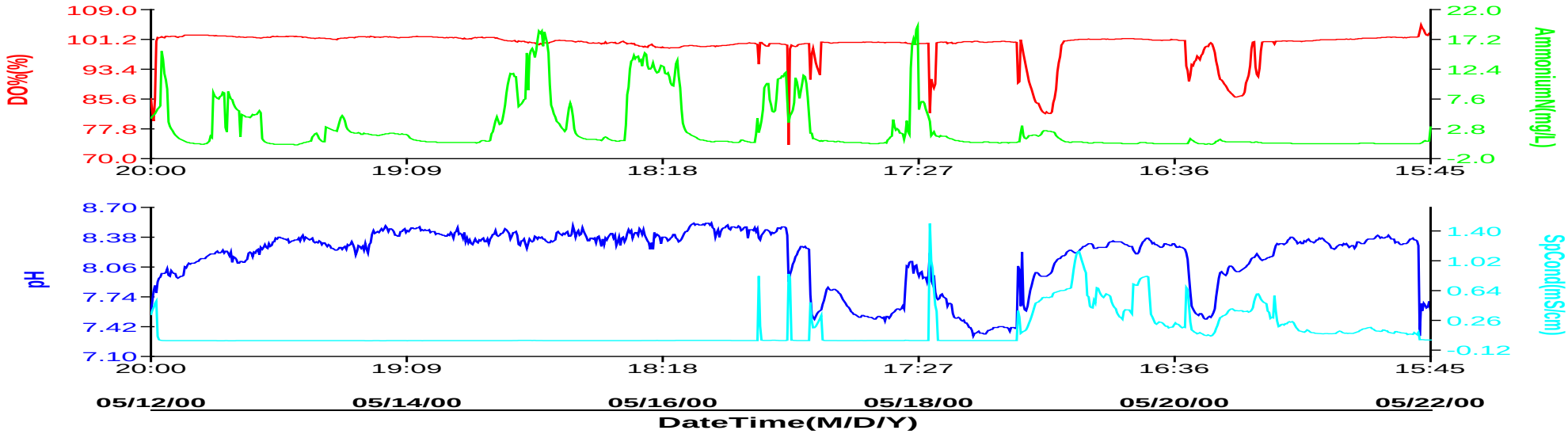
b) Hall brook Holbrook Lane manhole 544 Dunlop Arm



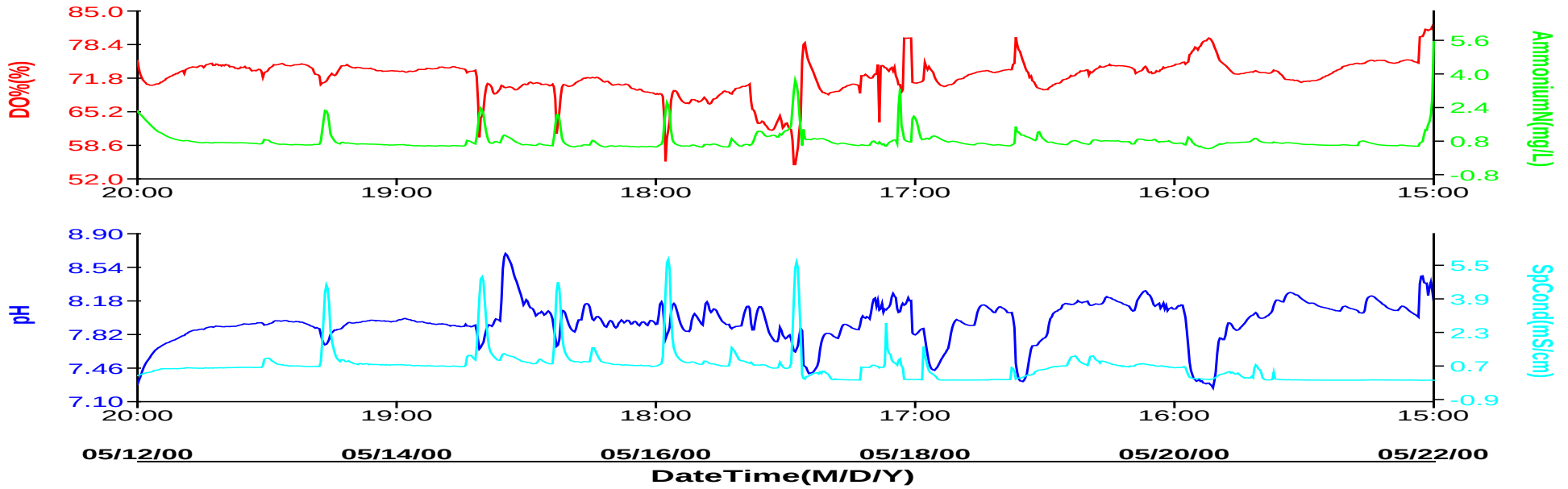
c) Hall brook Holbrook Lane manhole 533



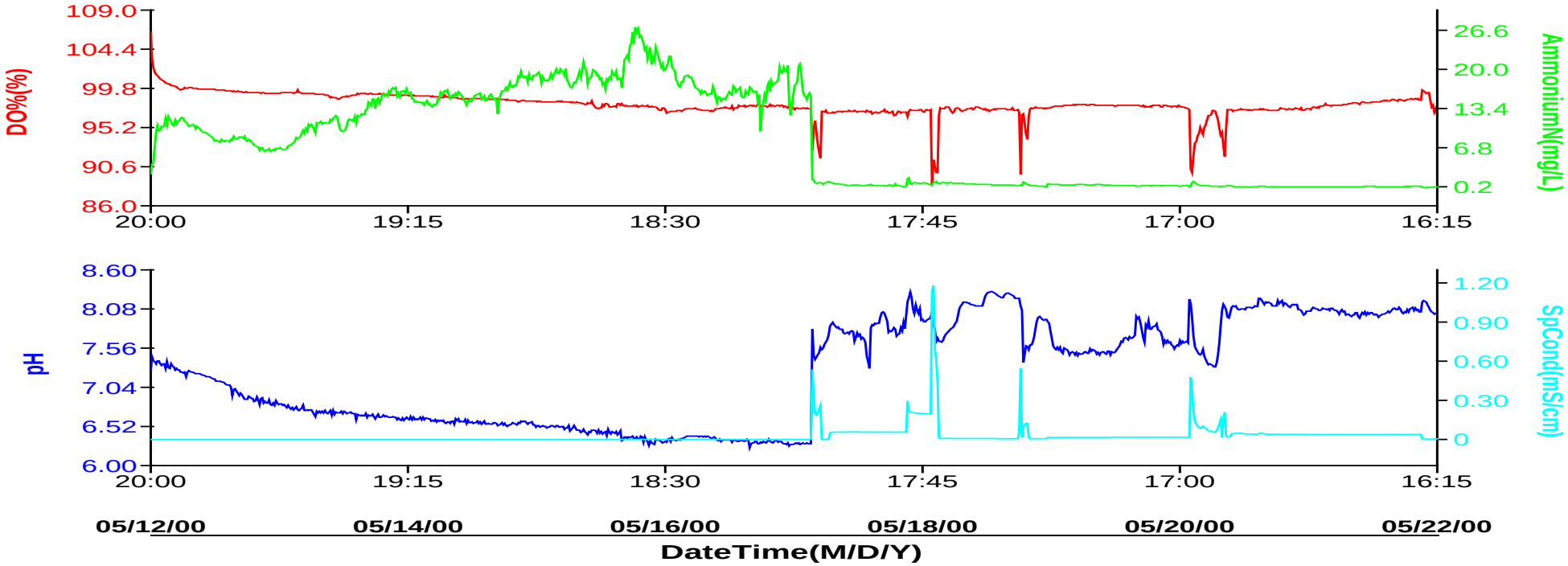
d) Hall Brook Holbrook Lane manhole 534 Dunlop Arm



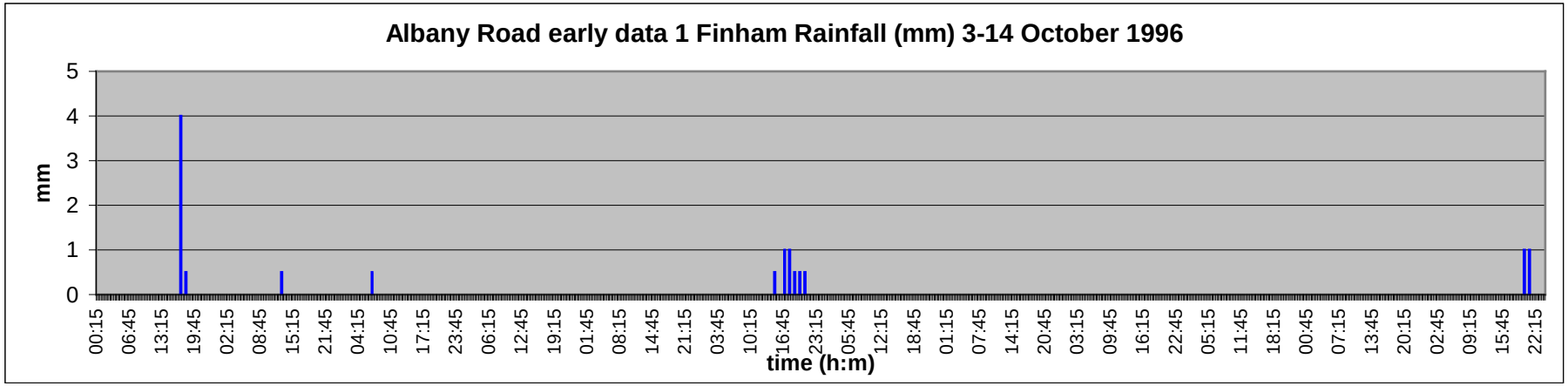
e) Hall Brook Foleshill Park upstream of Dunlop Interceptor



f) Hall Brook Foleshill Park downstream of Dunlop Interceptor

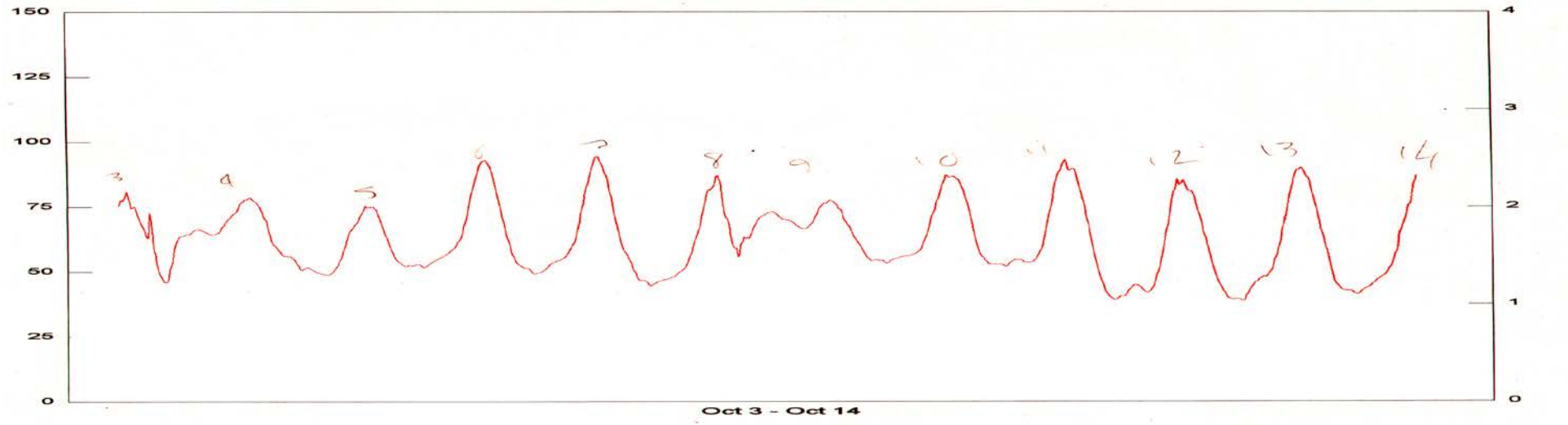


Albany Road Early data run1. 3-14 October 1996
Finham Rainfall



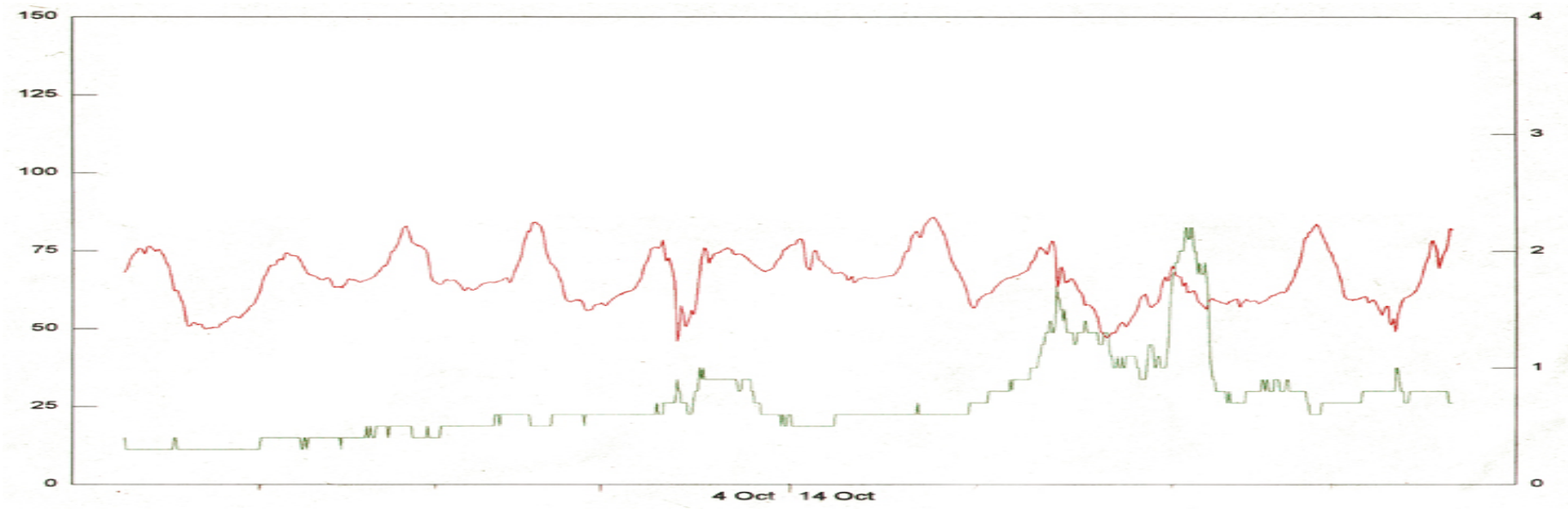
a)

a) River Sherbourne Waveley Road



Key: ——— **Dissolved Oxygen (% saturation)**

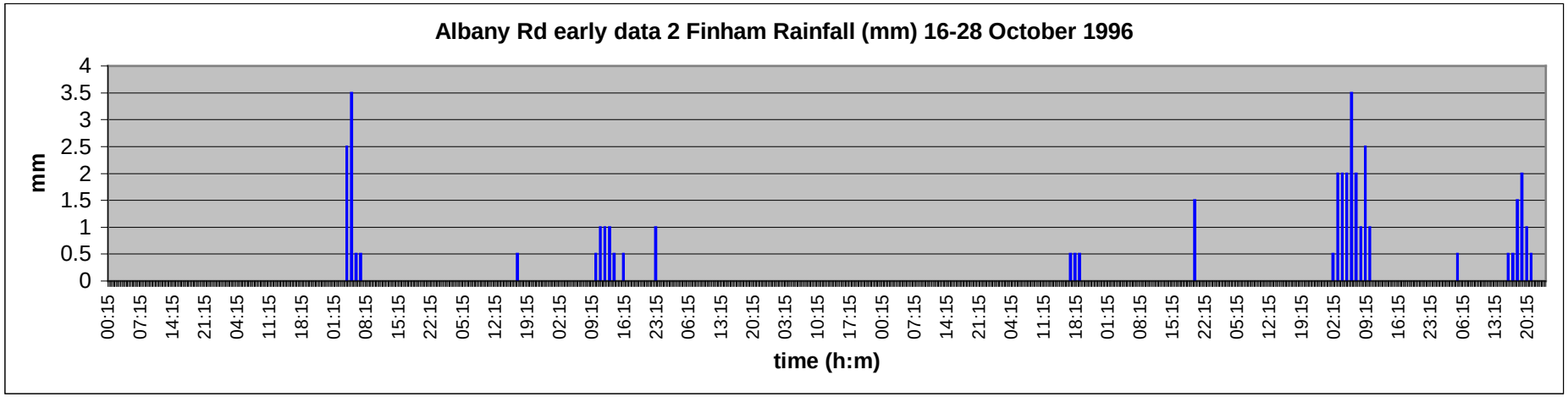
b) River Sherbourne Rudge Road 4-14 October 1996



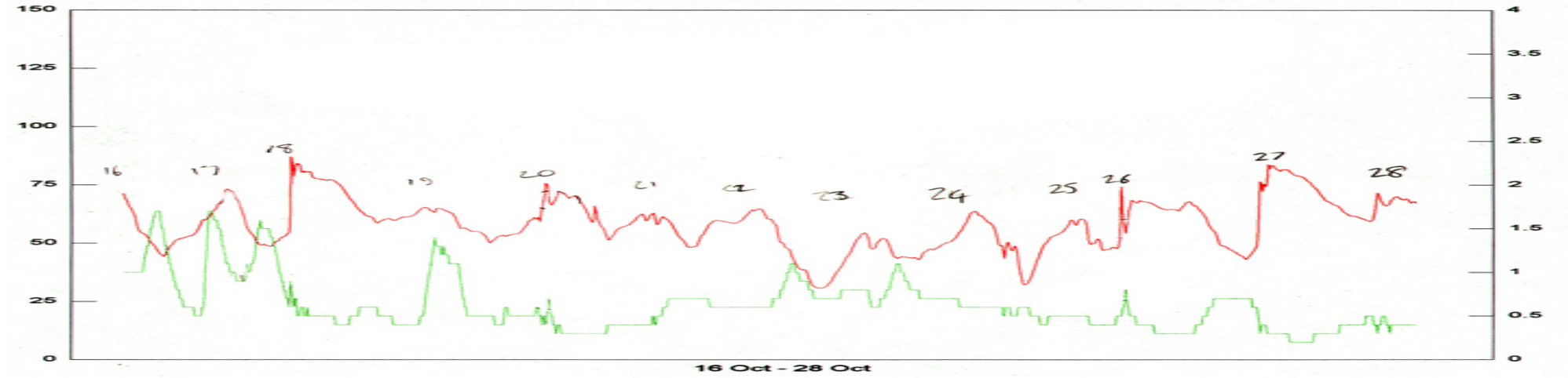
Key: **Dissolved Oxygen (% saturation)**

Ammonium (mgl^{-1})

Albany Road Early data run2. 16-28 October 1996
Finham Rainfall

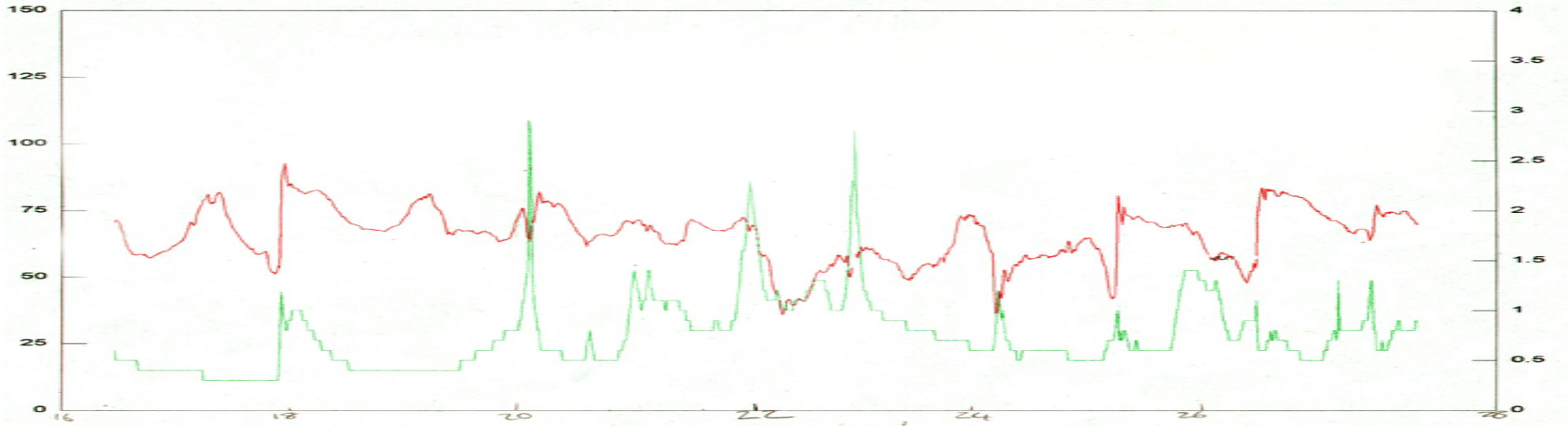


a) River Sherbourne Waveley Road



Key: Dissolved Oxygen (% saturation)
Ammonium (mgl^{-1})

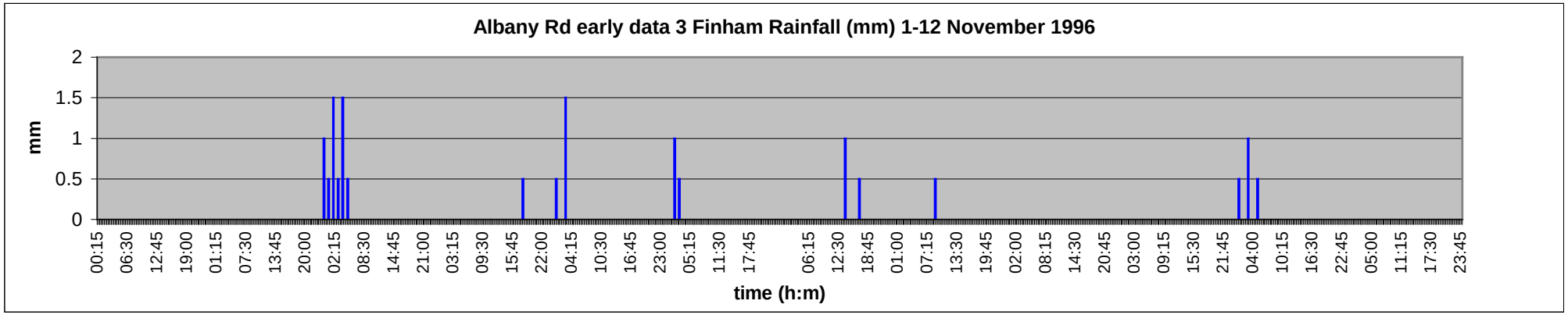
b) River Sherbourne Rudge Road



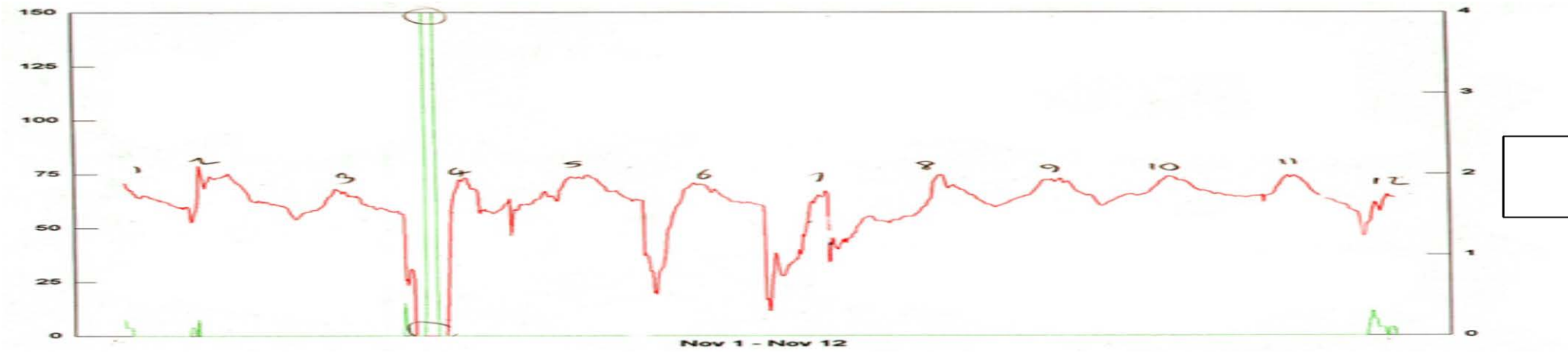
Key: **Dissolved Oxygen (% saturation)**

Ammonium (mgl^{-1})

Albany Road Early data run3. 1-12 November 1996
Finham Rainfall

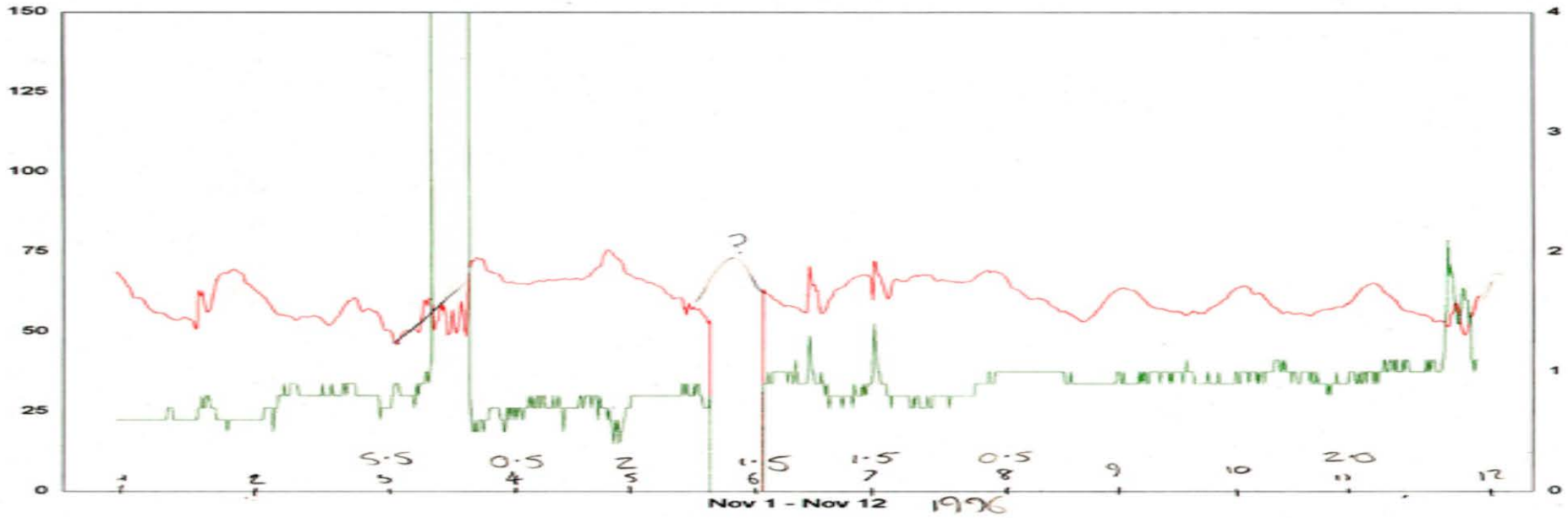


a) River Sherbourne Waveley Road



Key: Dissolved Oxygen (% saturation)
Ammonium (mgl^{-1})

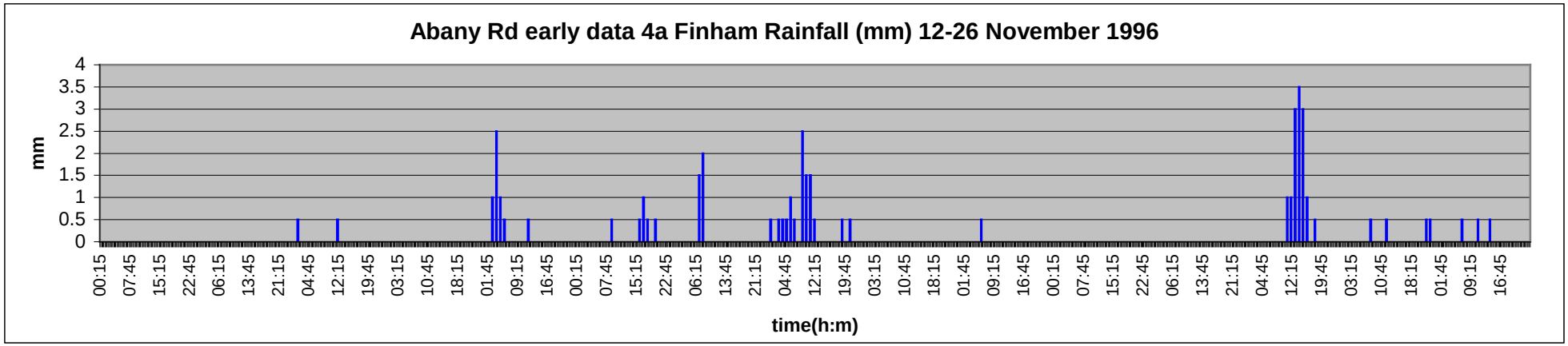
b) River Sherbourne Rudge Road



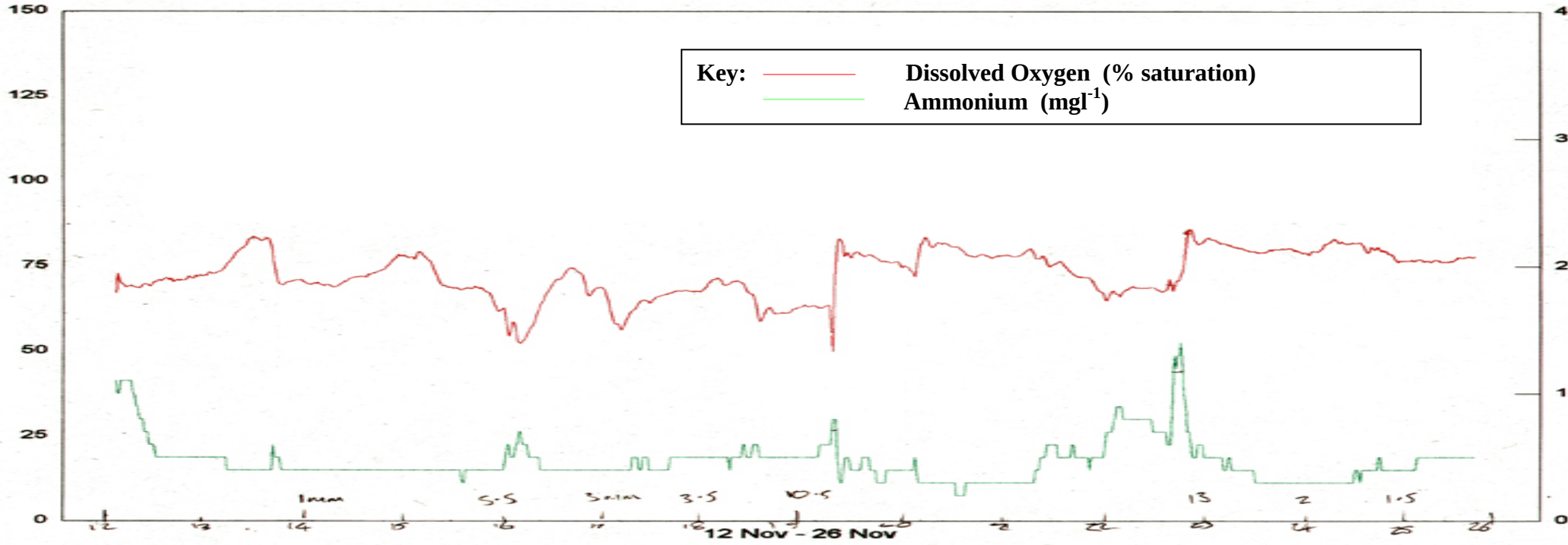
Key: **Dissolved Oxygen (% saturation)**

Ammonium (mgl^{-1})

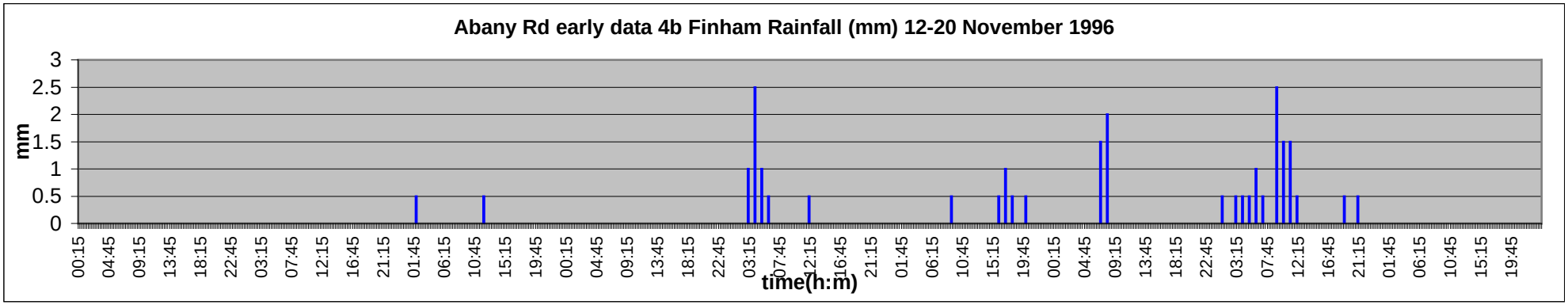
Albany Road Early data run4. 12-26 November 1996
Finham Rainfall
a) 12-26 November 1996



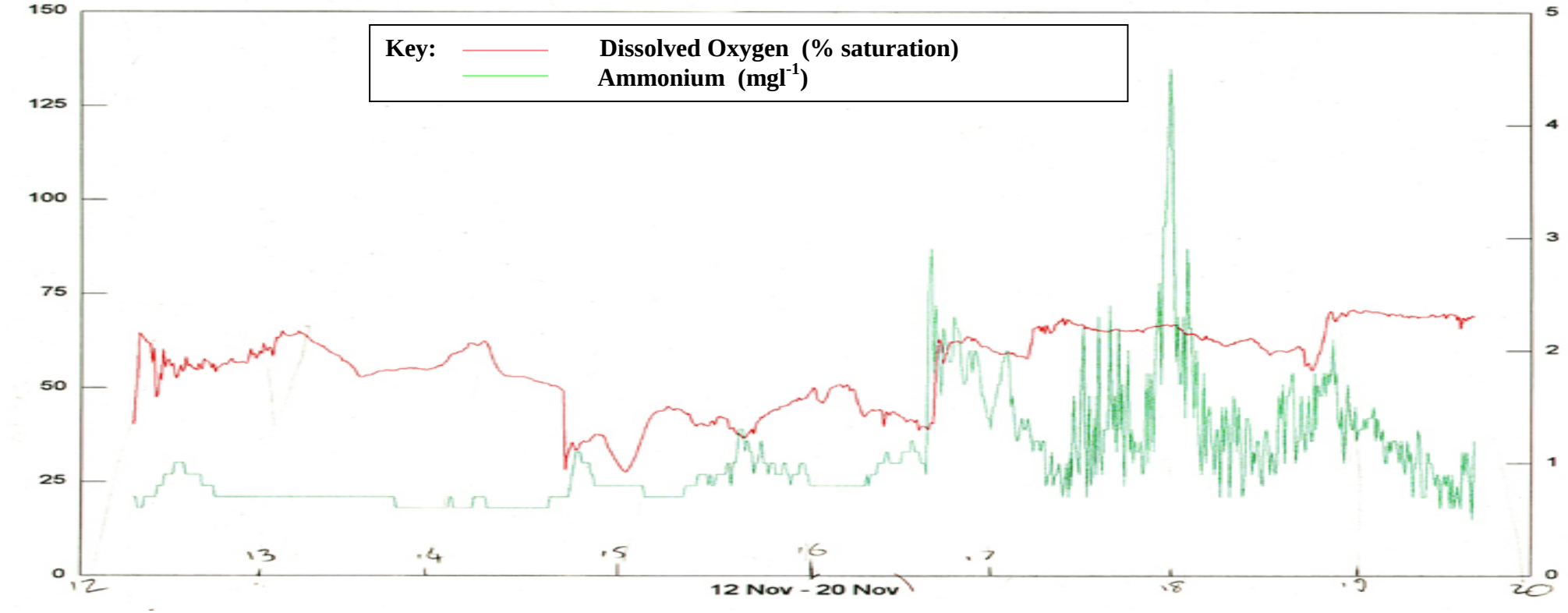
a) River Sherbourne Waveley Road



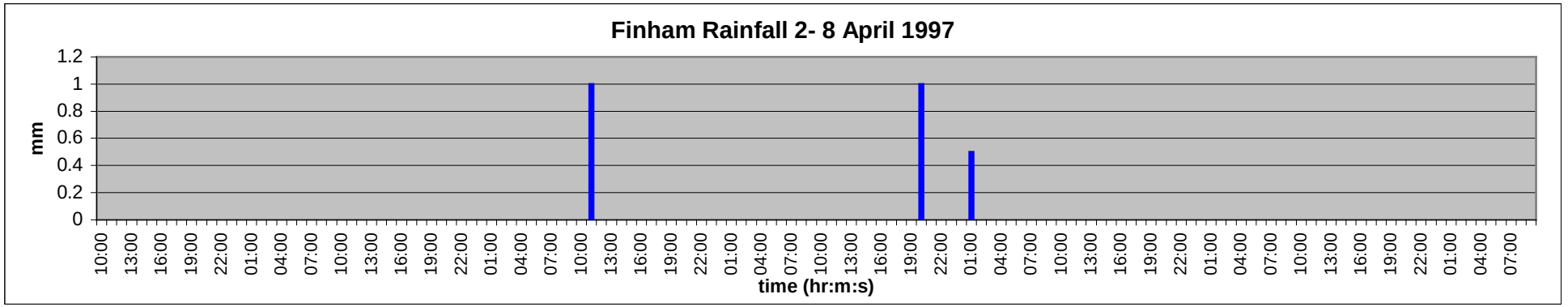
Finham Rainfall
a) 12-20 November 1996



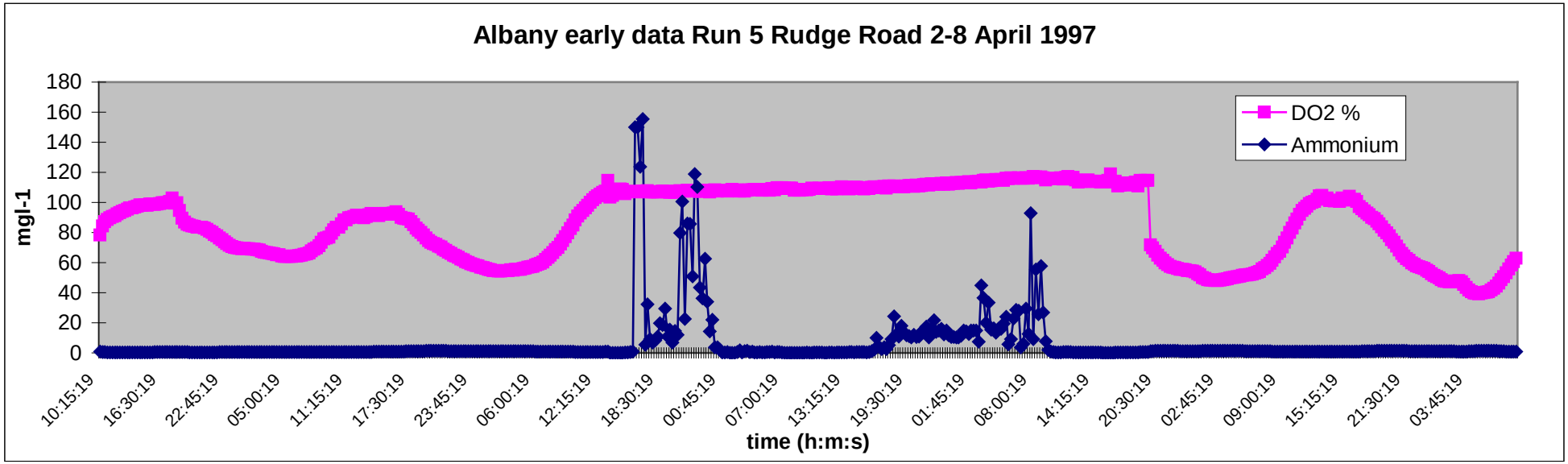
b) River Sherbourne Rudge Road



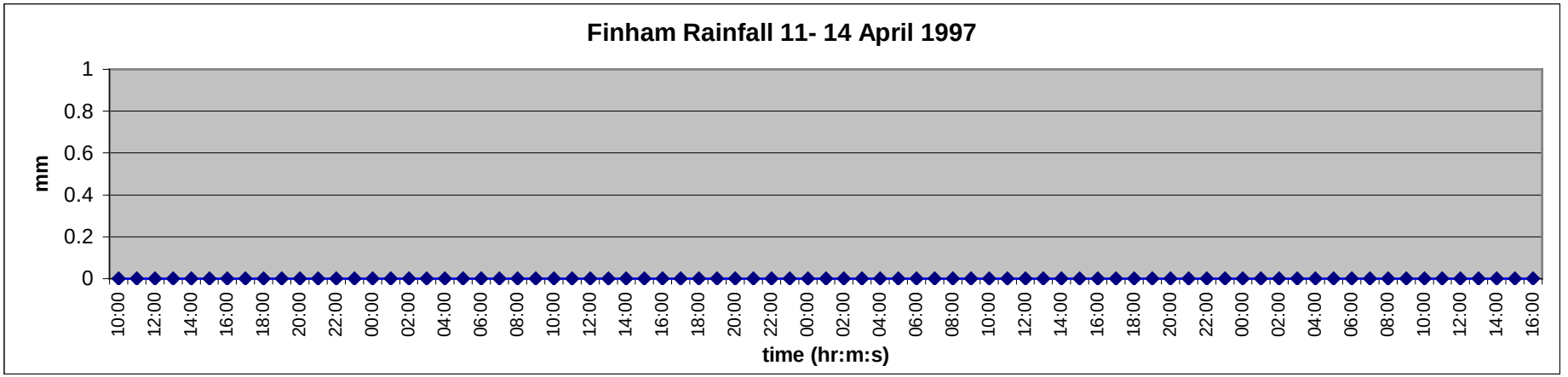
Albany Road Early data run5. 2-8 April 1997
Finham Rainfall



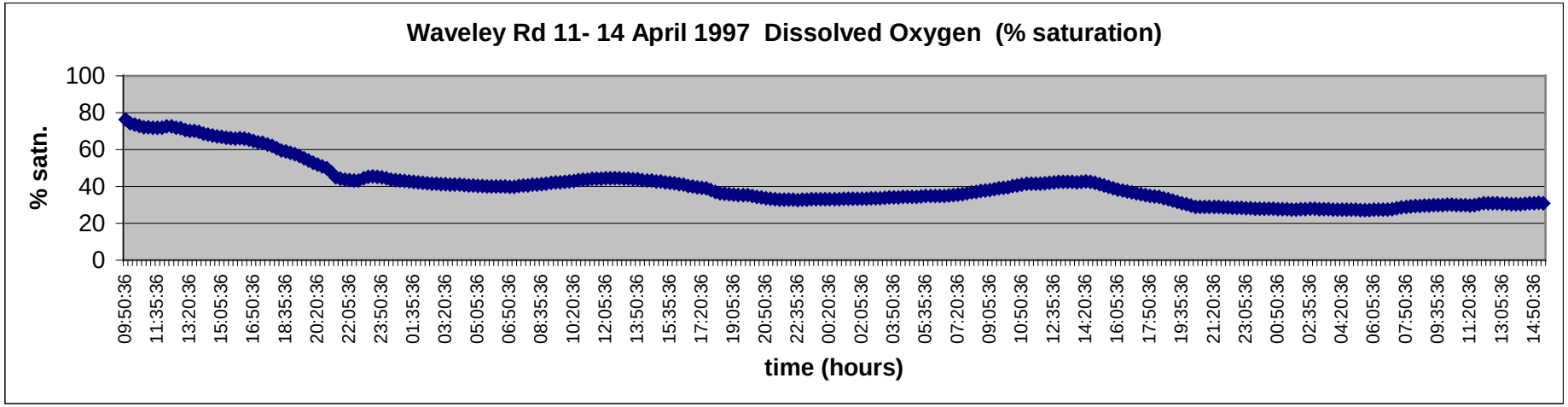
River Sherbourne Rudge Road



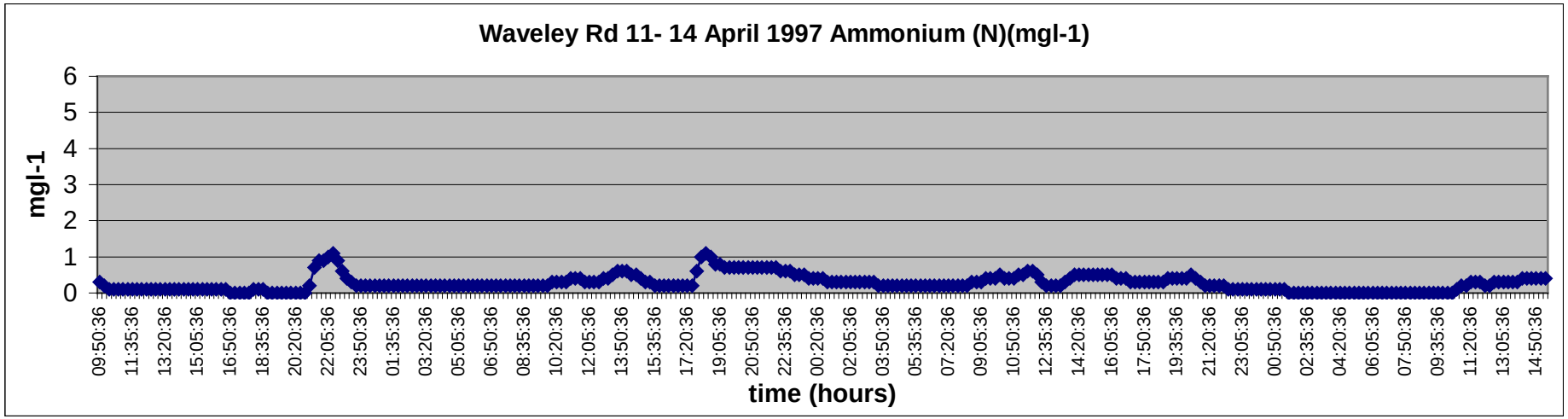
Albany Road Early data run6. 11-14 April 1997
Finham Rainfall



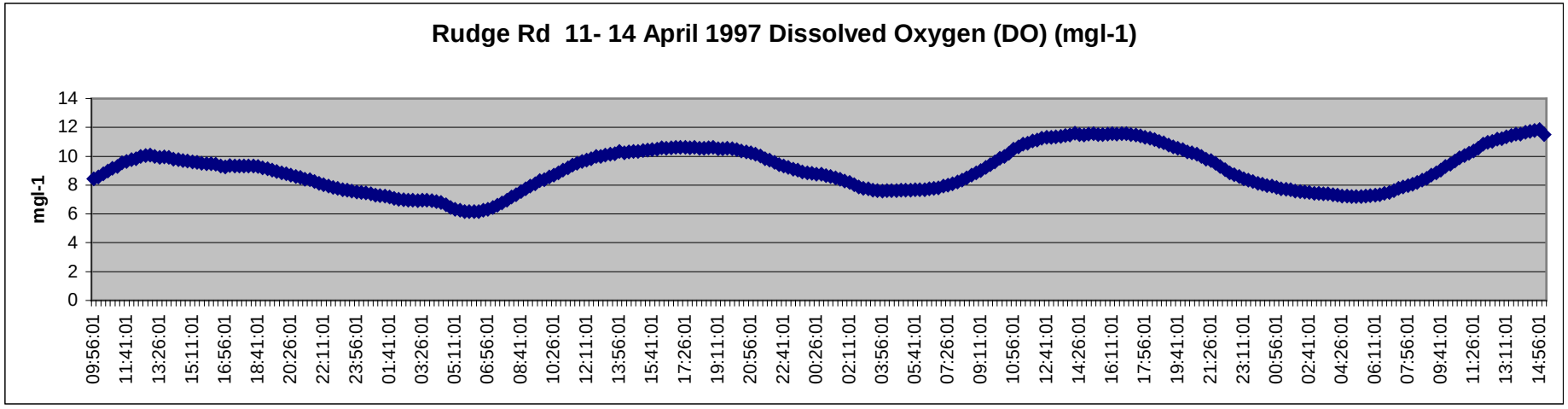
River Sherbourne Rudge Road a) Dissolved oxygen



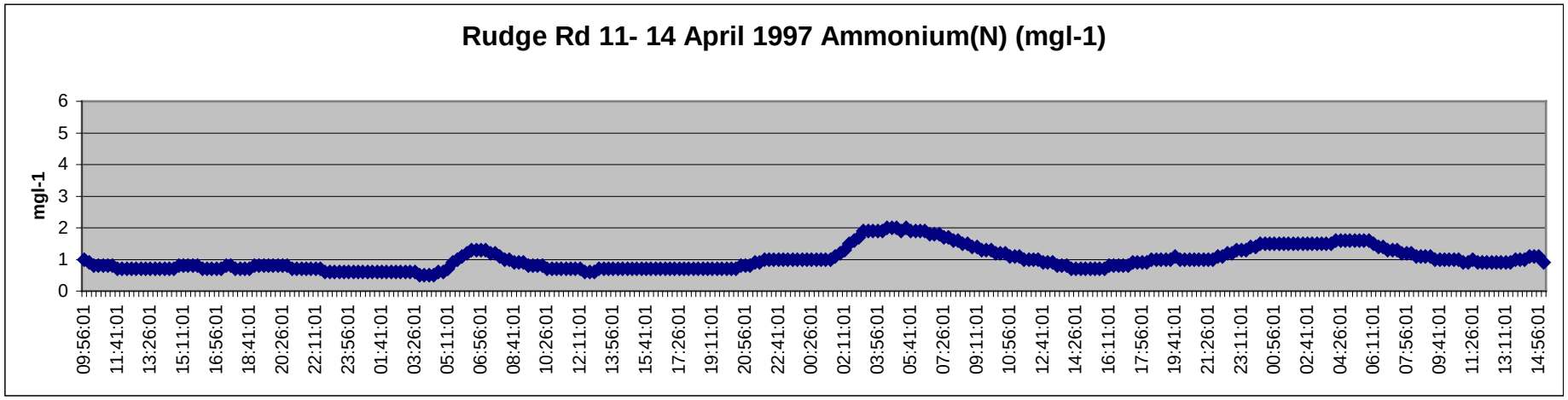
b) Ammonium



River Sherbourne Rudge Road a) Dissolved Oxygen

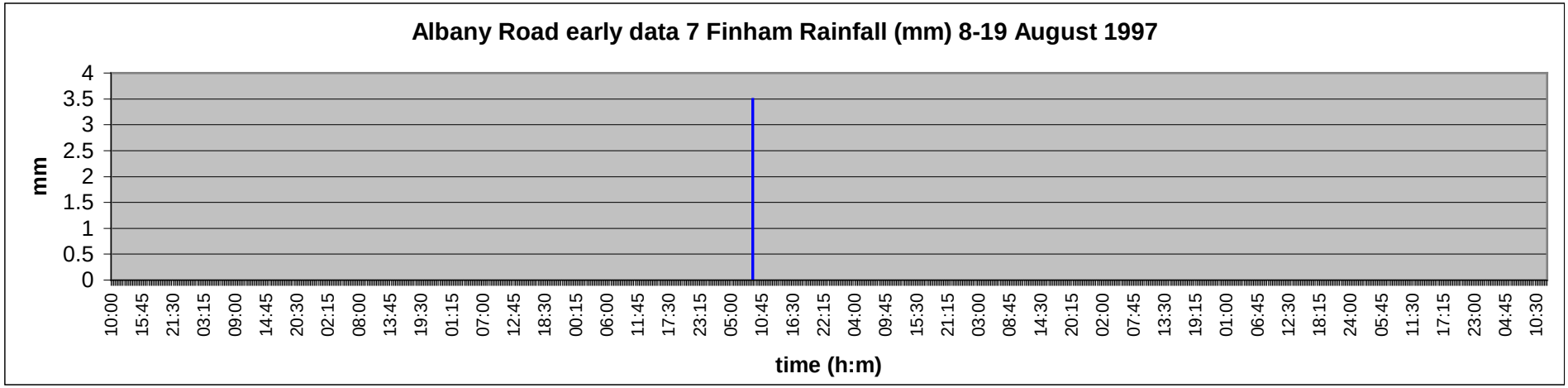


b) Ammonium

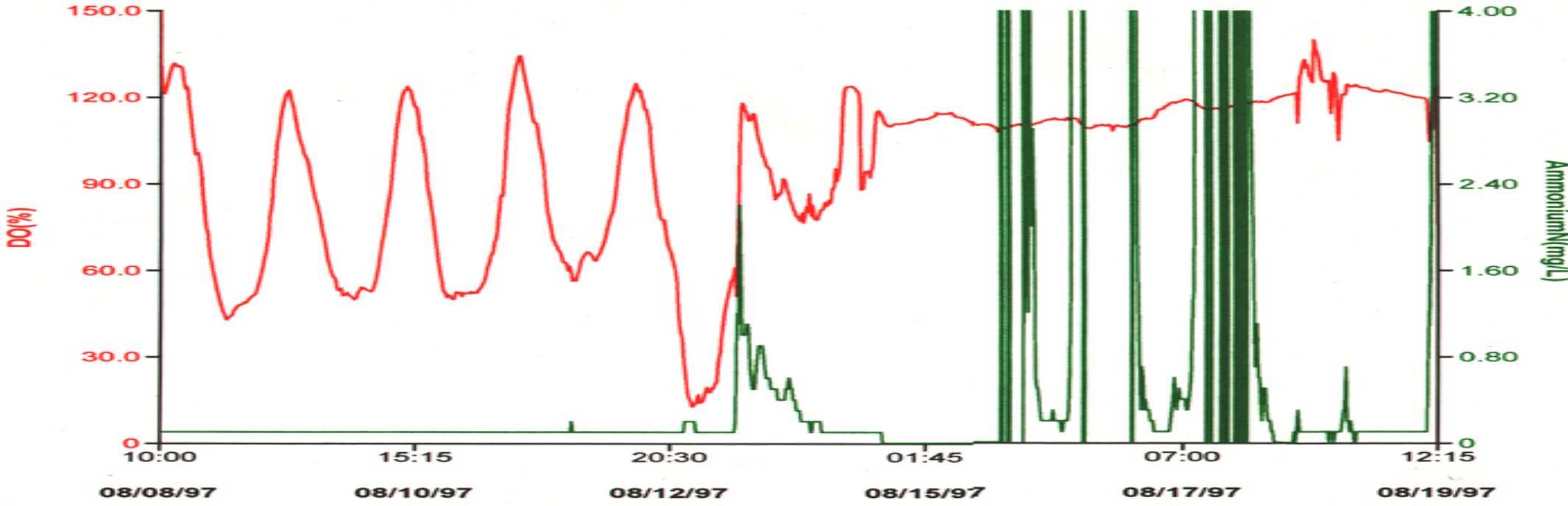


Charterhouse not added asyet

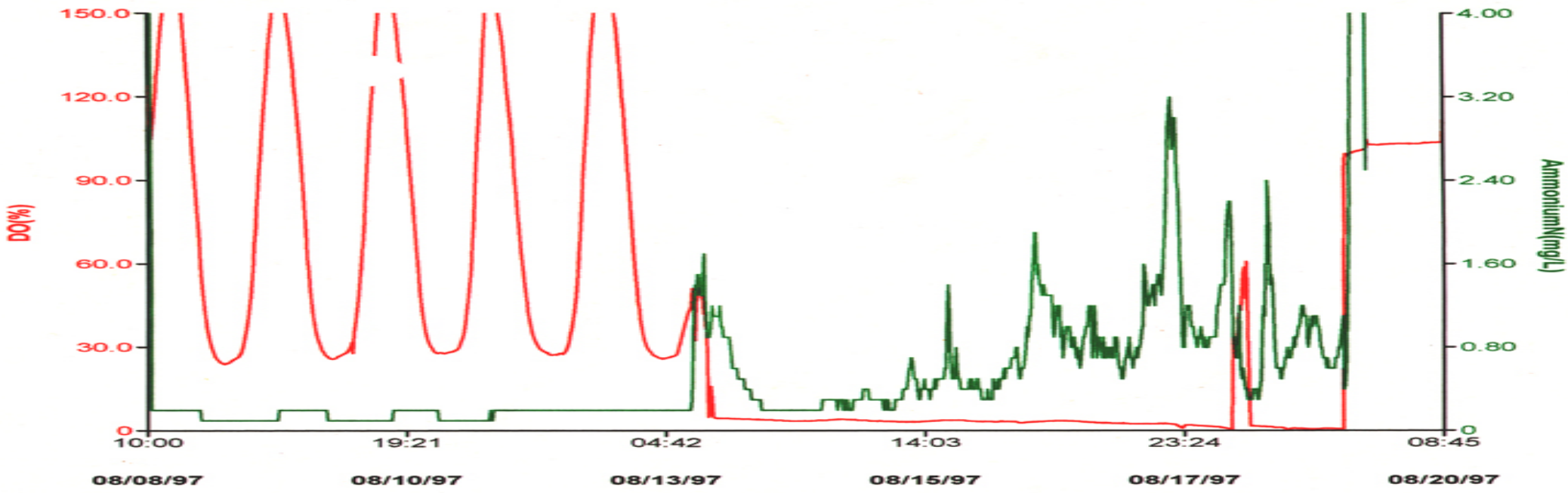
Albany Road Early data run7. 8-19 August 1997
Finham Rainfall



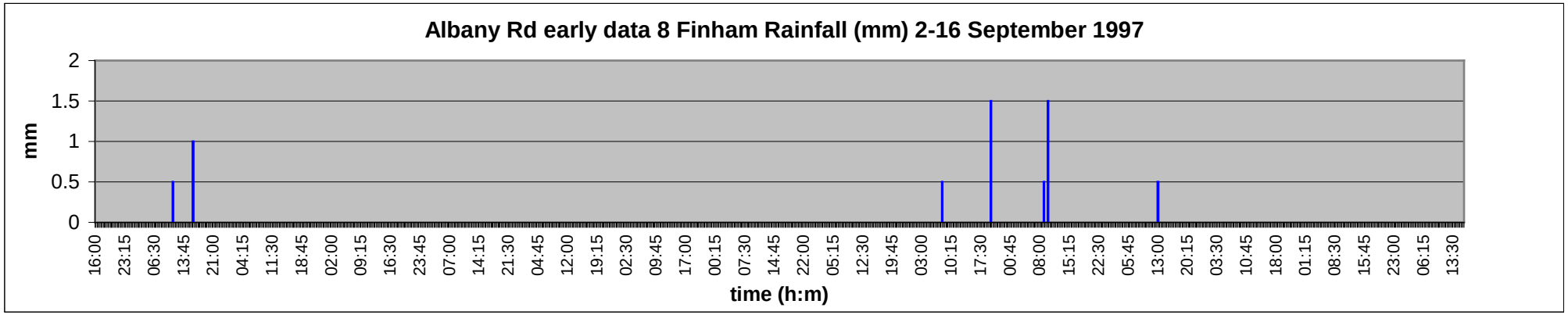
a) River Sherbourne Waveley Road



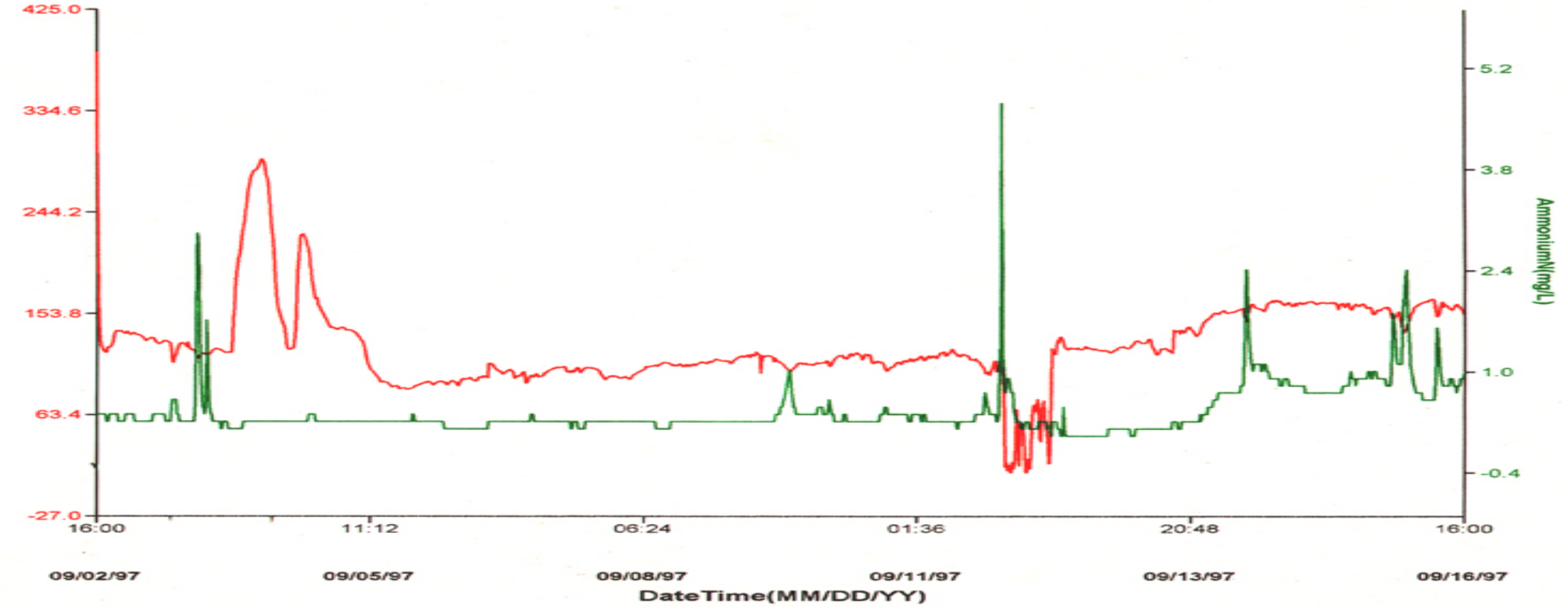
b) River Sherbourne Rudge Road



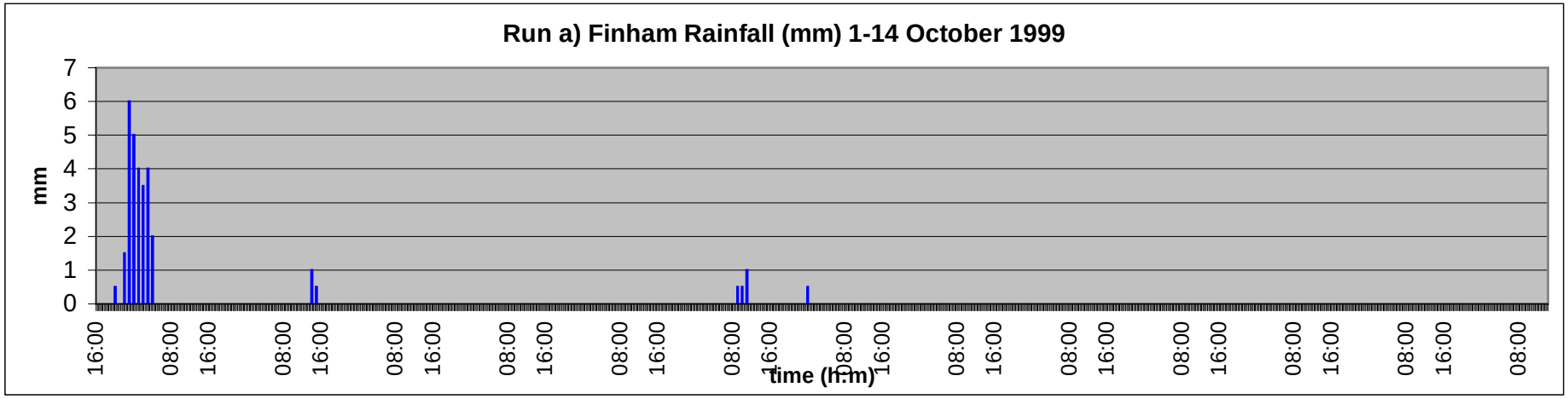
Albany Road Early data run8. 2-16 September 1997
Finham Rainfall

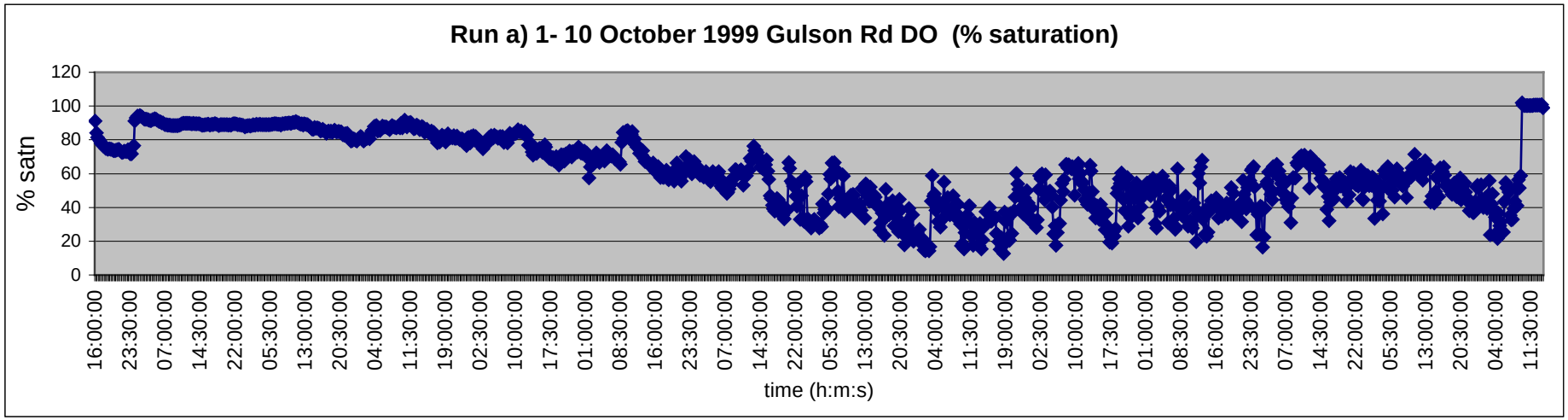


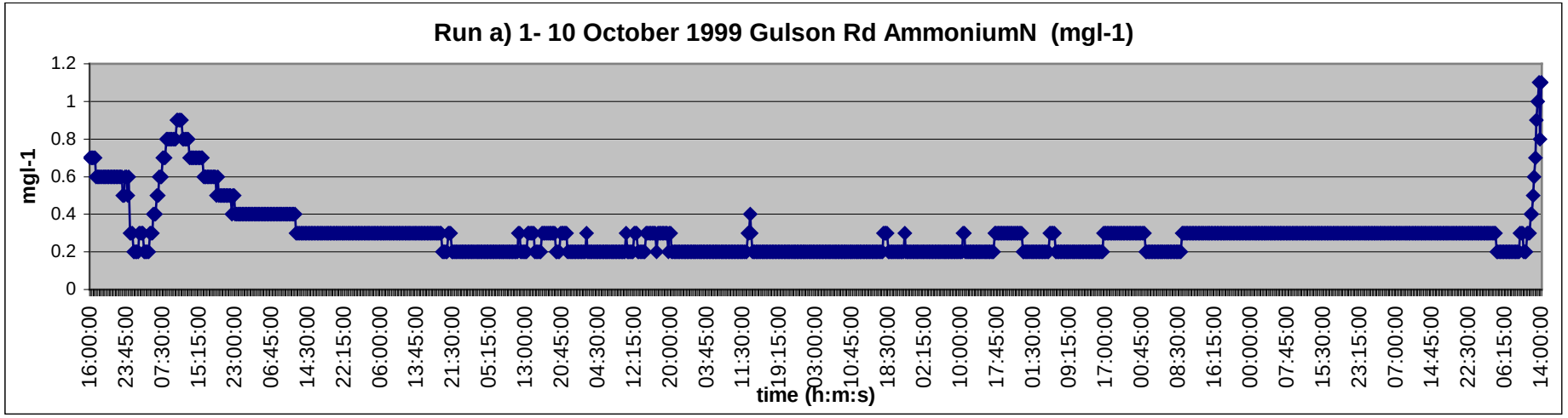
River Sherbourne Gosford Street

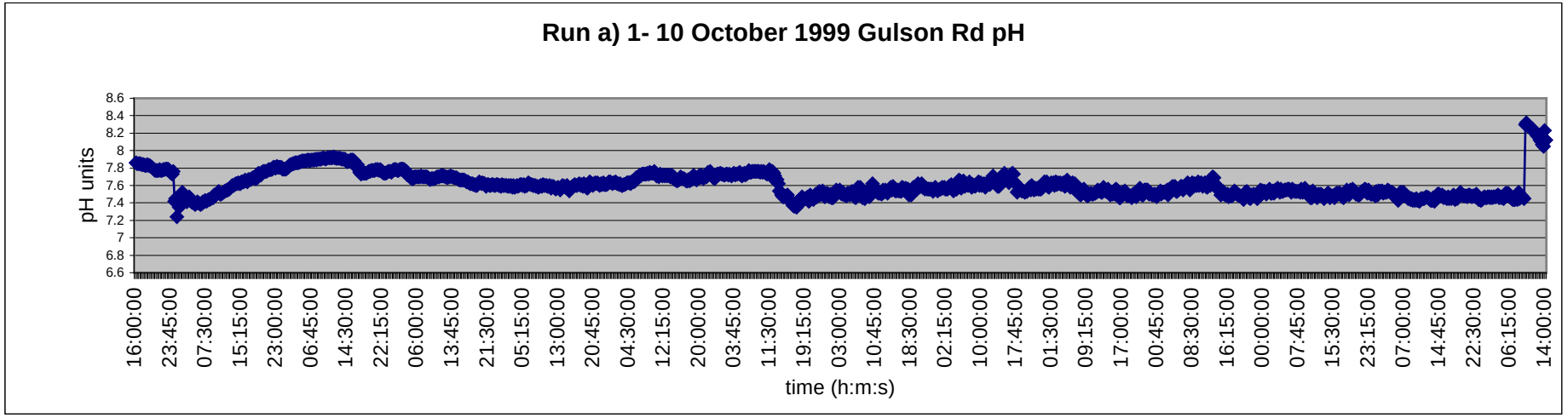


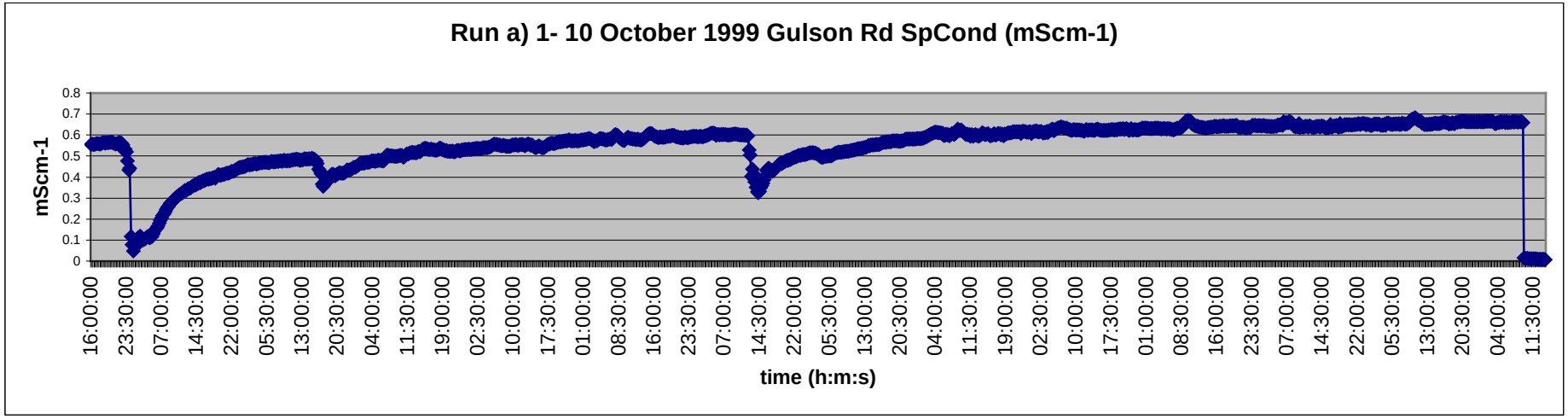
Pre-remedial continuous monitors, October 1999 to September 2000
Run a) 1- 14 October 1999 (Gulson Road only – Vincent Rd monitor failure)





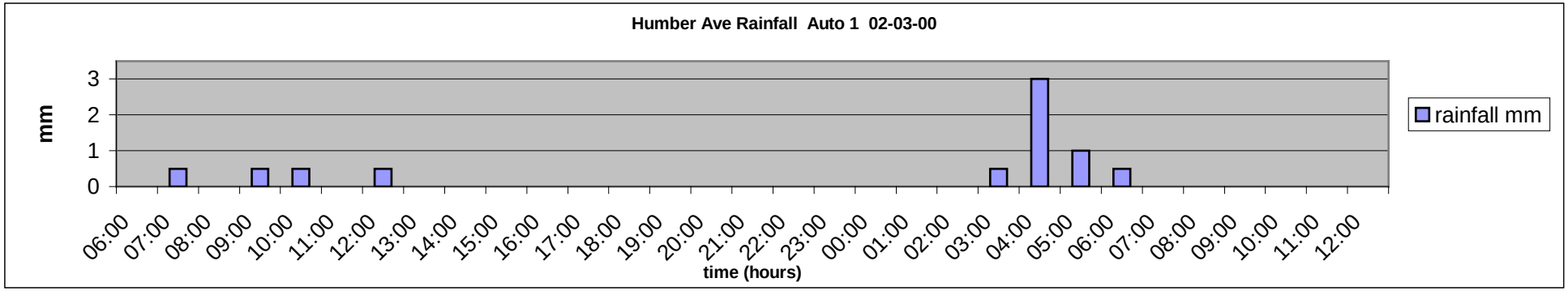

Run a) 1- 10 October 1999 Gulson Rd AmmoniumN (mgl-1)
mgl-1
1.2
1
0.8
0.6
0.4
0.2
0
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
17:00:00
00:45:00
08:30:00
16:15:00
00:00:00
07:45:00
15:30:00
23:15:00
07:00:00
14:45:00
22:30:00
06:15:00
14:00:00
time (h:m:s)


Run a) 1- 10 October 1999 Gulson Rd pH
pH units
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
6.6
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
17:00:00
00:45:00
08:30:00
16:15:00
00:00:00
07:45:00
15:30:00
23:15:00
07:00:00
14:45:00
22:30:00
06:15:00
14:00:00
time (h:m:s)


Run a) 1- 10 October 1999 Gulson Rd SpCond (mScm-1)
mScm-1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
16:00:00
23:30:00
07:00:00
14:30:00
22:00:00
05:30:00
13:00:00
20:30:00
04:00:00
11:30:00
19:00:00
02:30:00
10:00:00
17:30:00
01:00:00
08:30:00
16:00:00
23:30:00
07:00:00
14:30:00
22:00:00
05:30:00
13:00:00
20:30:00
04:00:00
11:30:00
19:00:00
02:30:00
10:00:00
17:30:00
01:00:00
08:30:00
16:00:00
23:30:00
07:00:00
14:30:00
22:00:00
05:30:00
13:00:00
20:30:00
04:00:00
11:30:00
time (h:m:s)

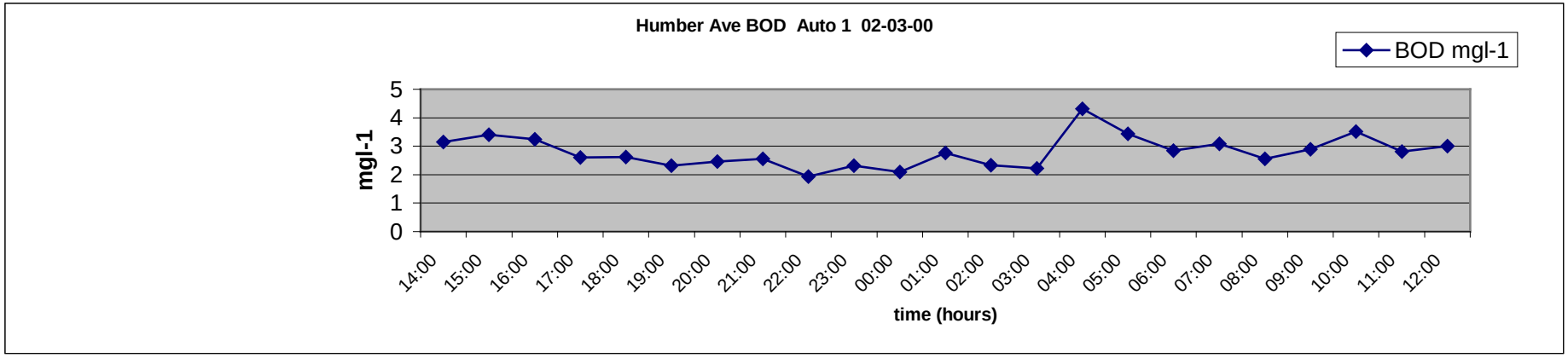
Auto 1 Humber Avenue 2-3 March 2000

a) Rainfall

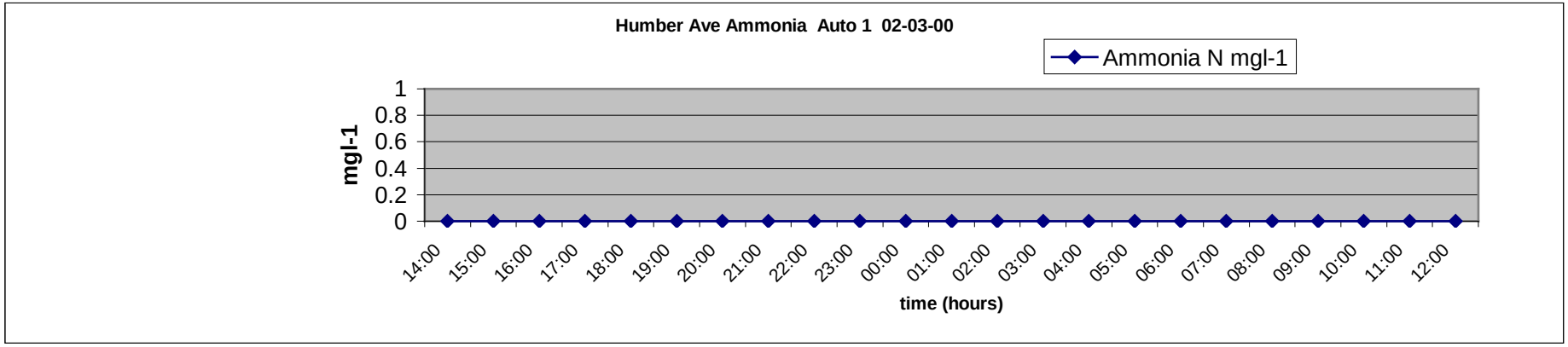


baseline period	initial rainfall period	Dry period	peak rainfall period	post storm

b) Biochemical Oxygen Demand

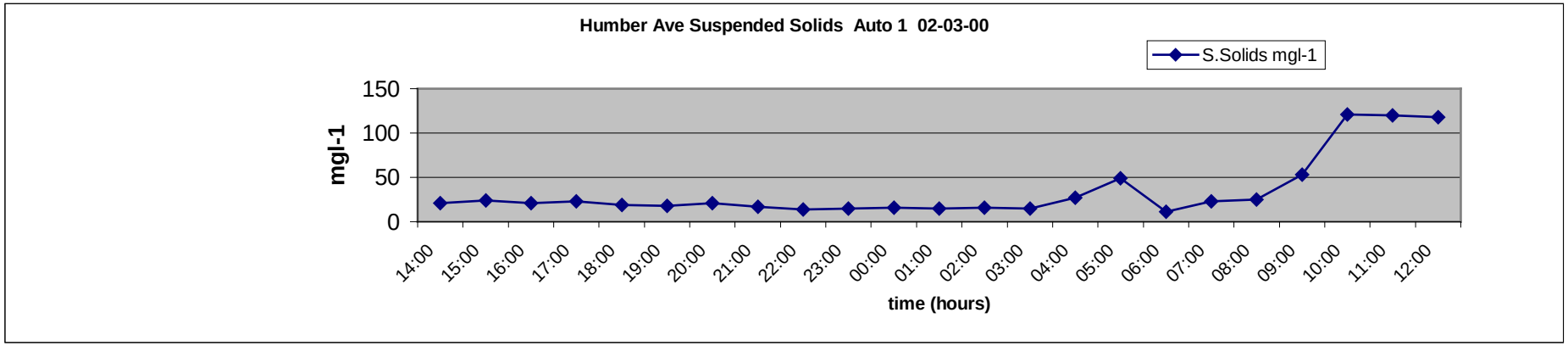


c) Ammonia

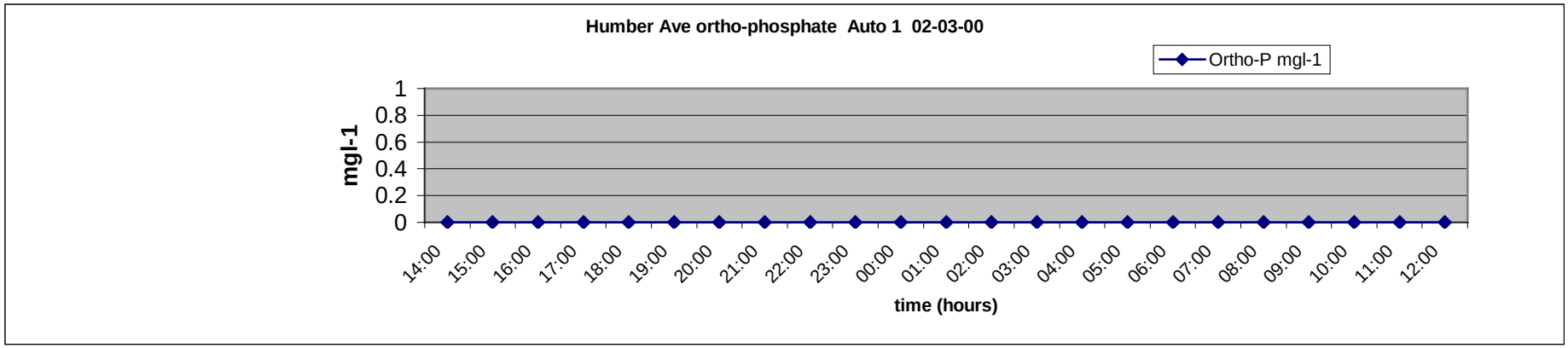


baseline period	initial rainfall period	Dry period	peak rainfall period	post storm

d) Suspended Solids

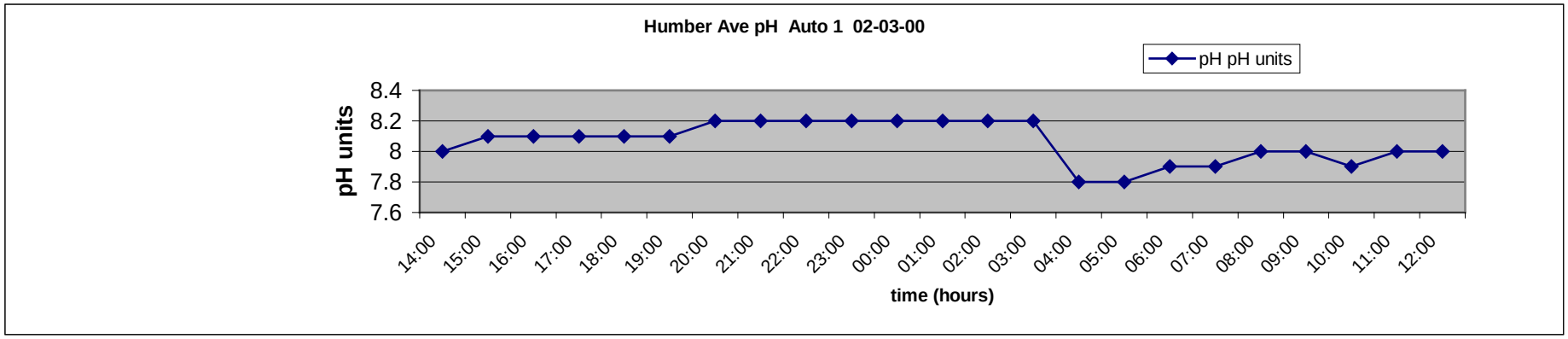


e) Ortho-phosphate

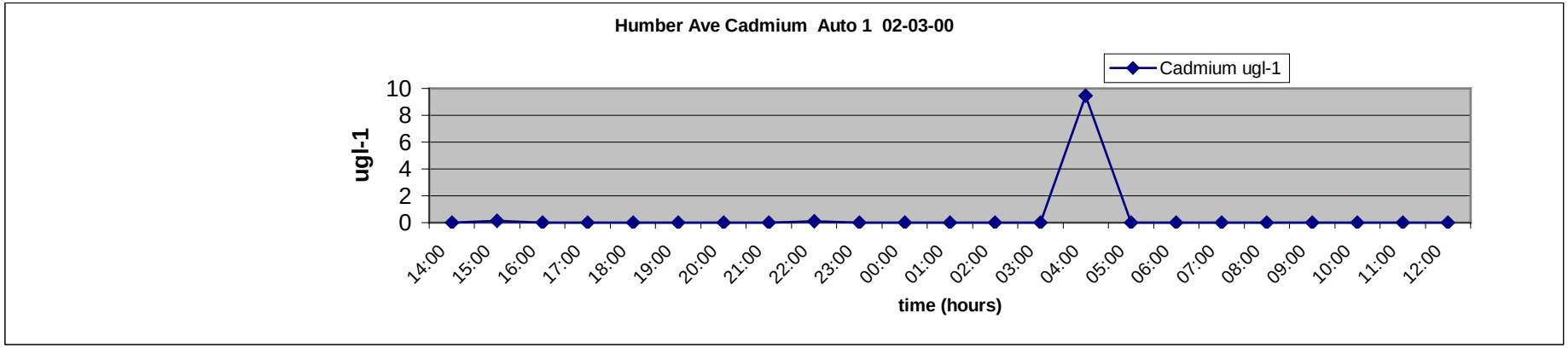


baseline period	initial rainfall period	Dry period	peak rainfall period	post storm

f) pH

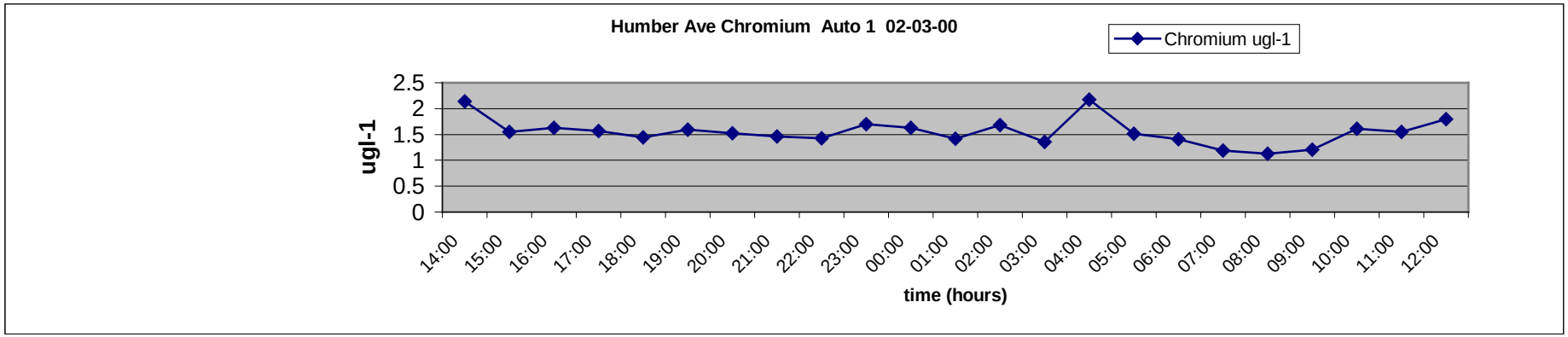


g) Cadmium

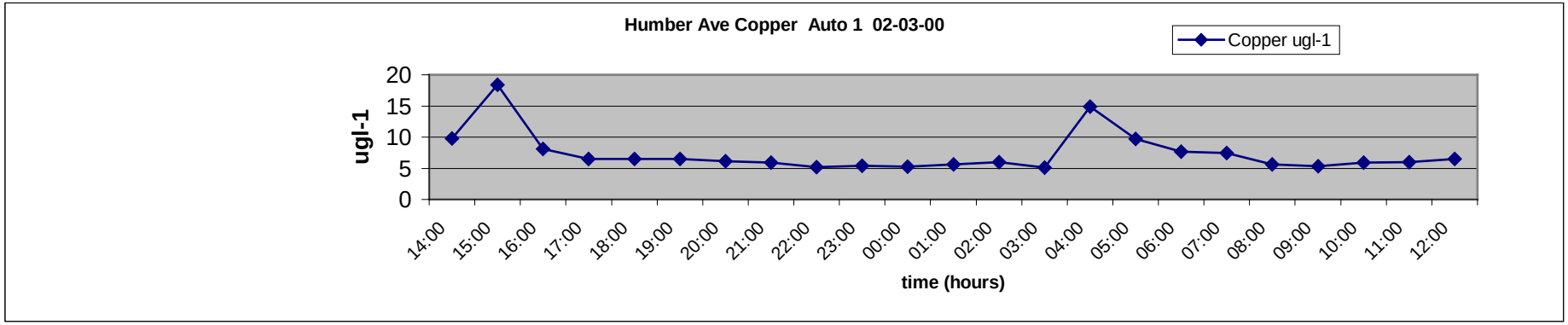


baseline period	initial rainfall period	Dry period	peak rainfall period	post storm

h) Chromium

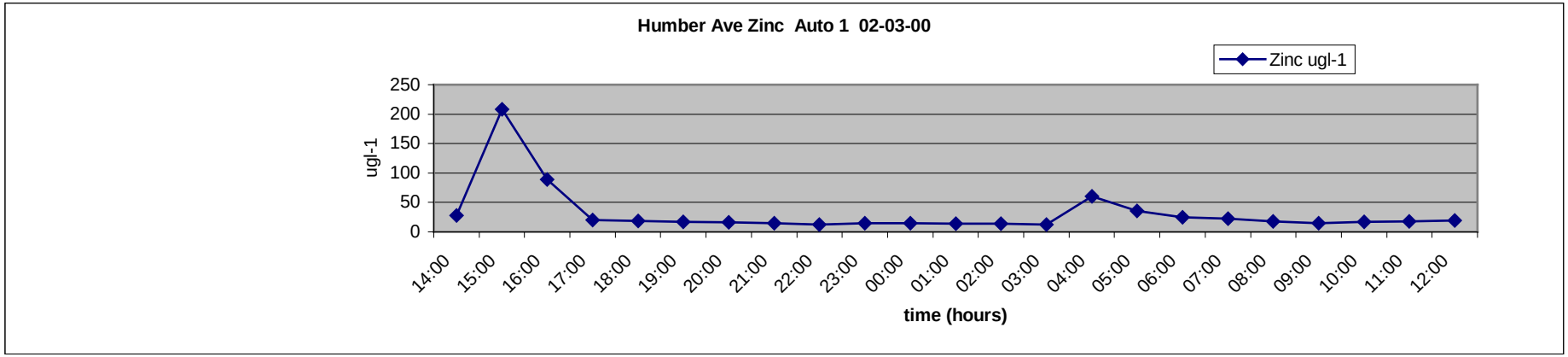


i) Copper

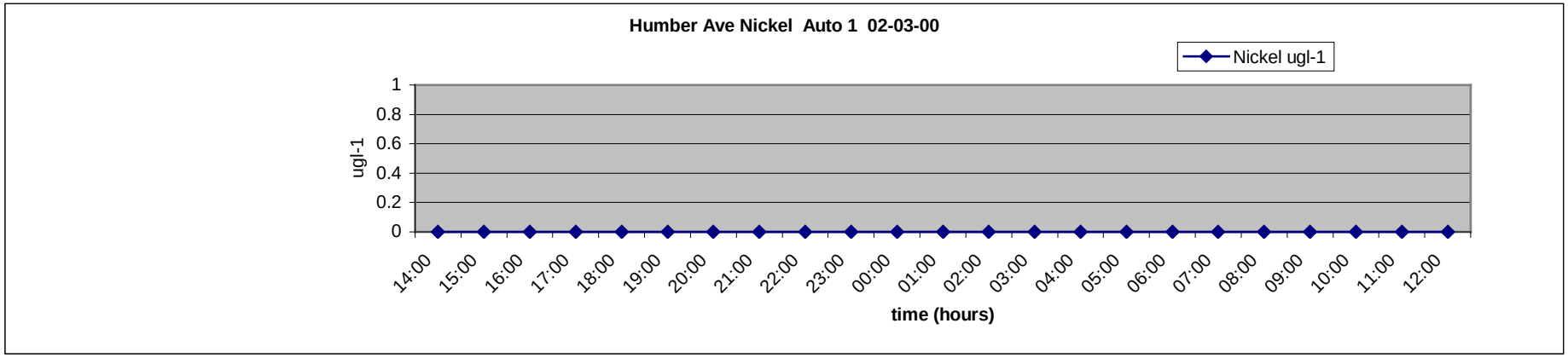


baseline period	initial rainfall period	Dry period	peak rainfall period	post storm

j) Zinc



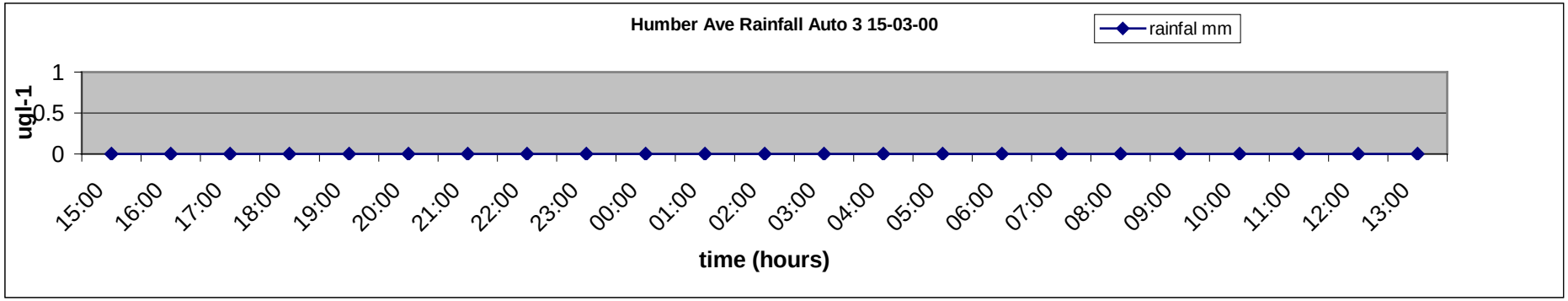
k) Nickel



baseline period	initial rainfall period	Dry period	peak rainfall period	post storm

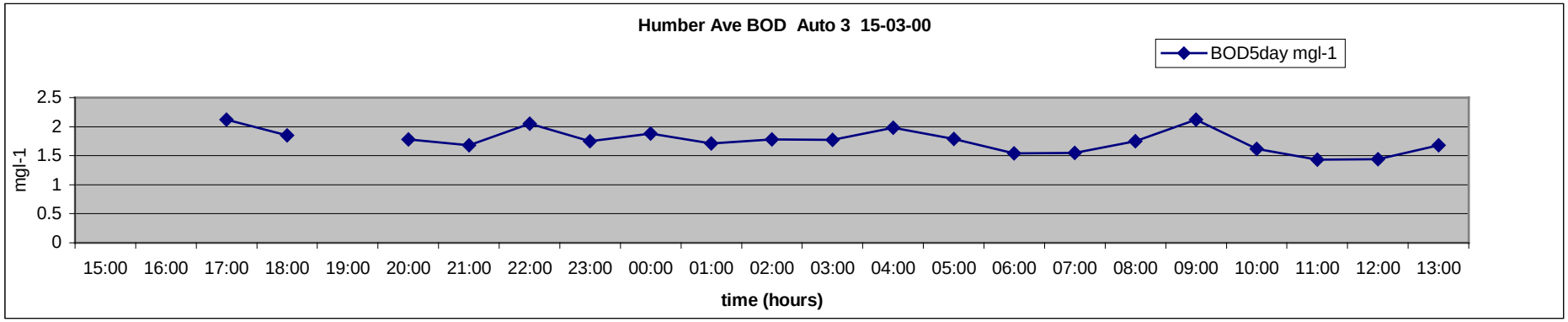
Auto 3 Humber Avenue 15-16 March 2000 – dry weather event

a) Rainfall

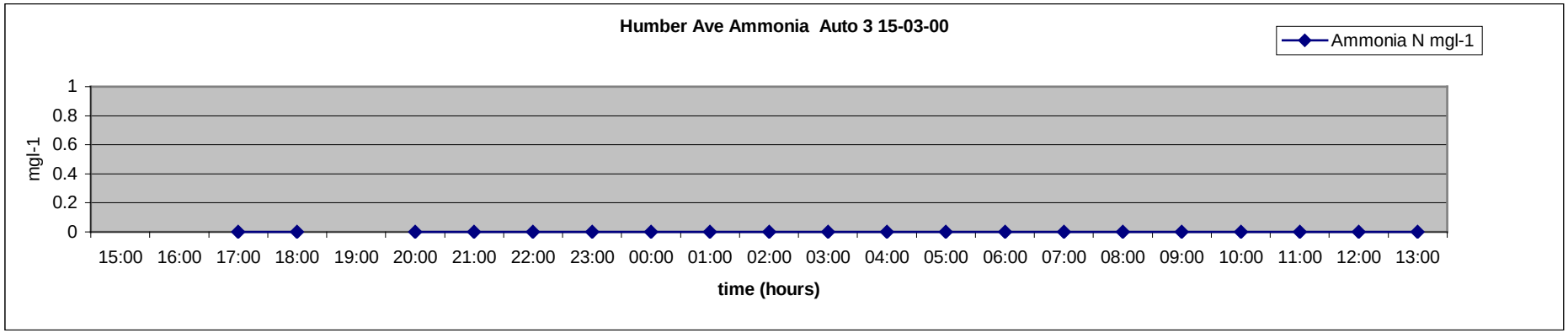


Dry period

b) Biochemical Oxygen Demand BOD

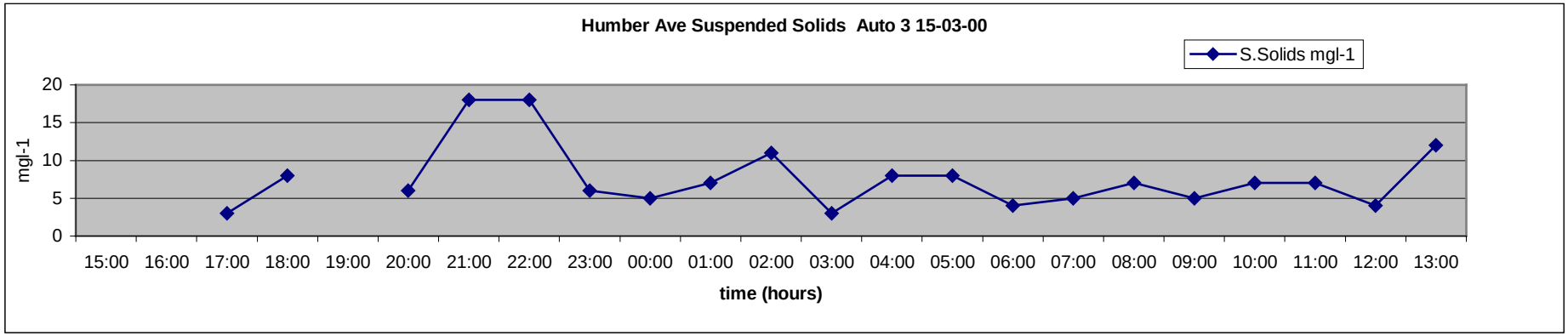


c) Ammonia

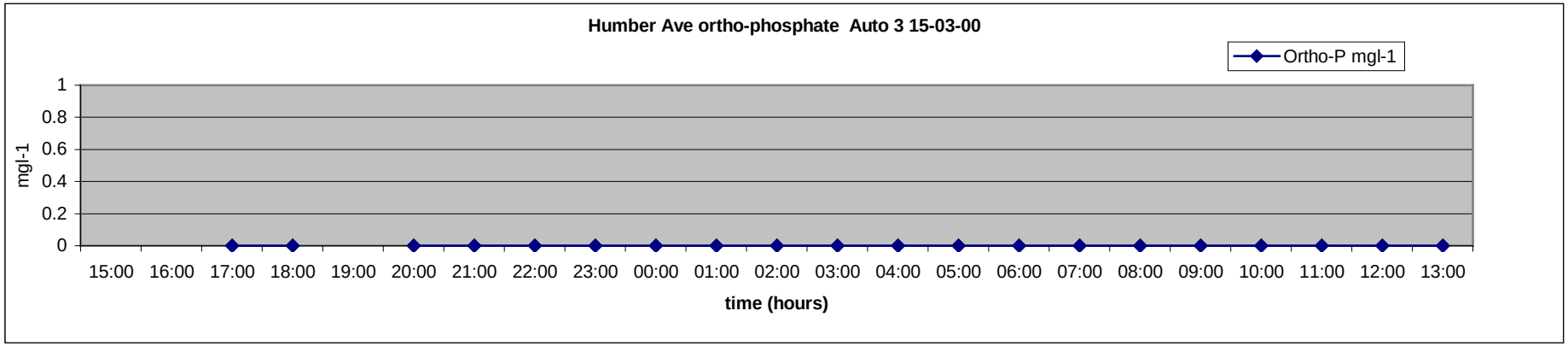


Dry period

d) Suspended Solids

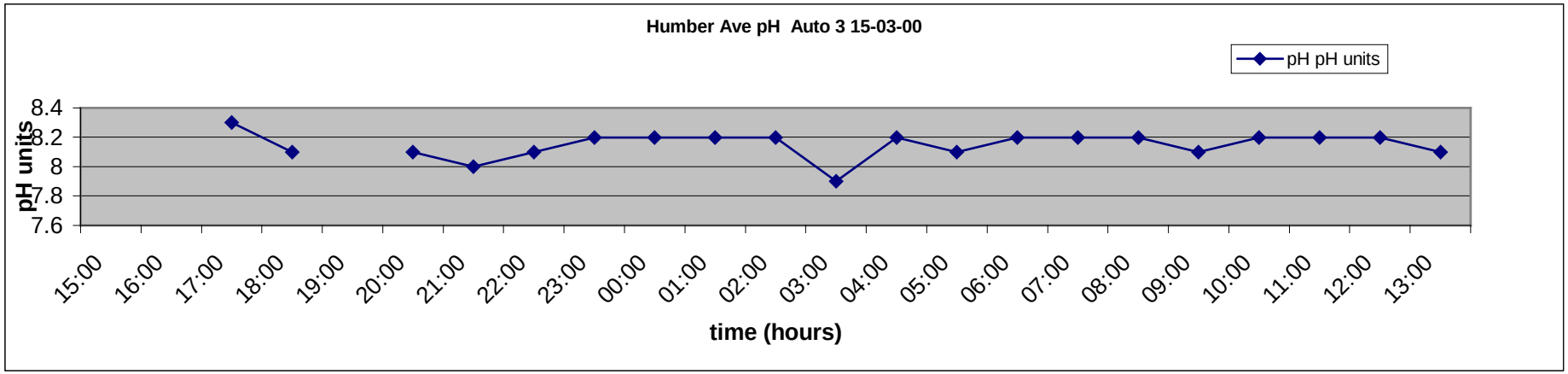


e) Ortho-phosphates

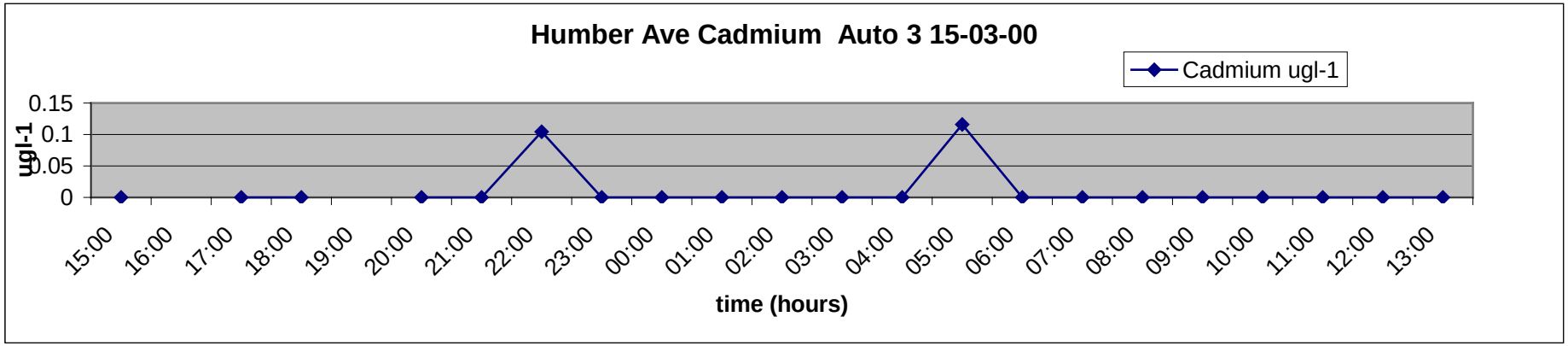


Dry period

f) pH

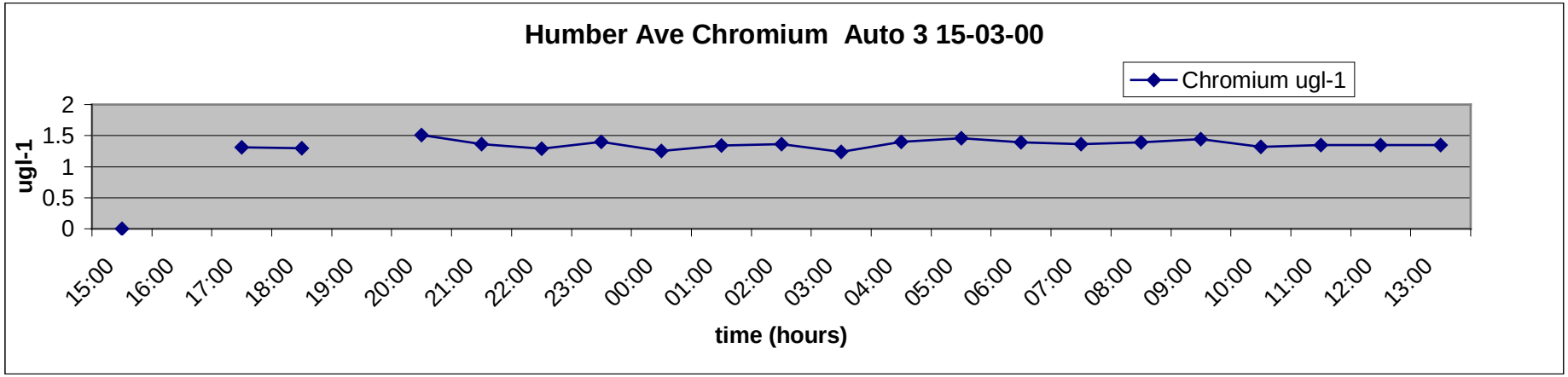


g) Cadmium

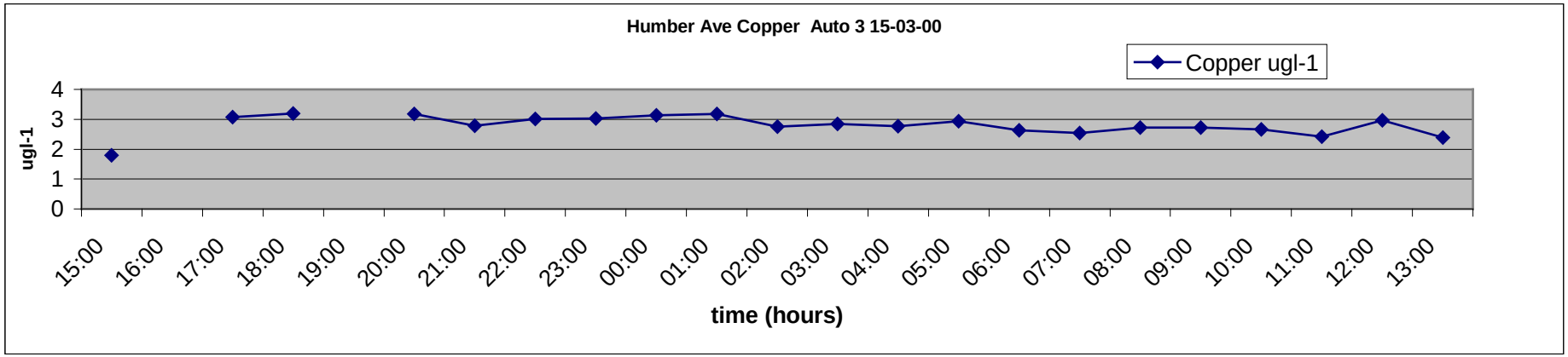


Dry period

h) Chromium

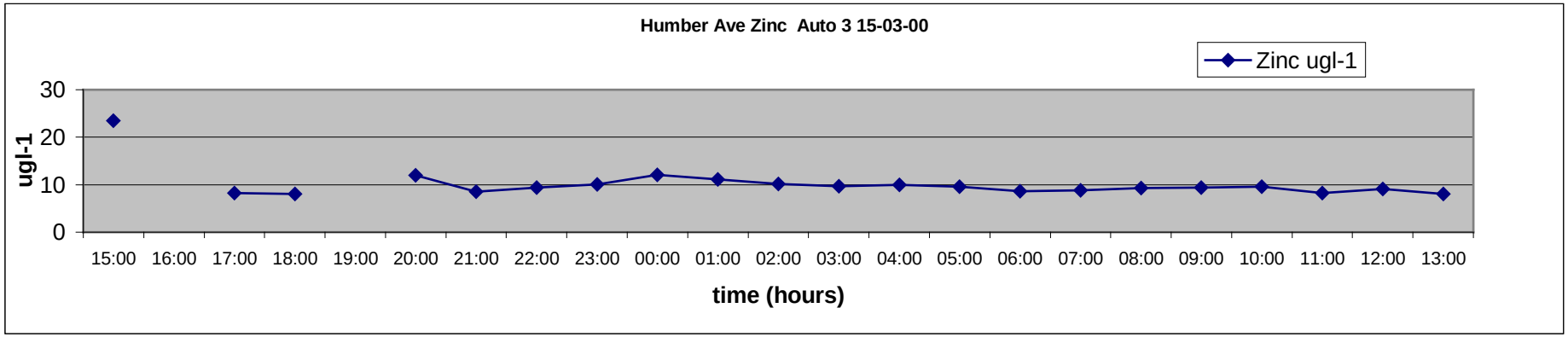


i) Copper

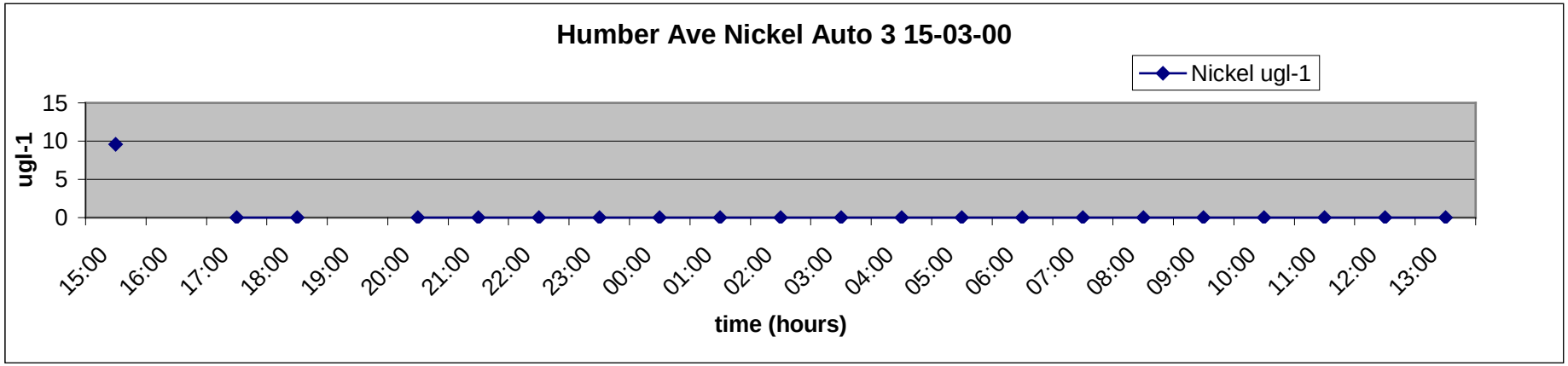


Dry period

j) Zinc

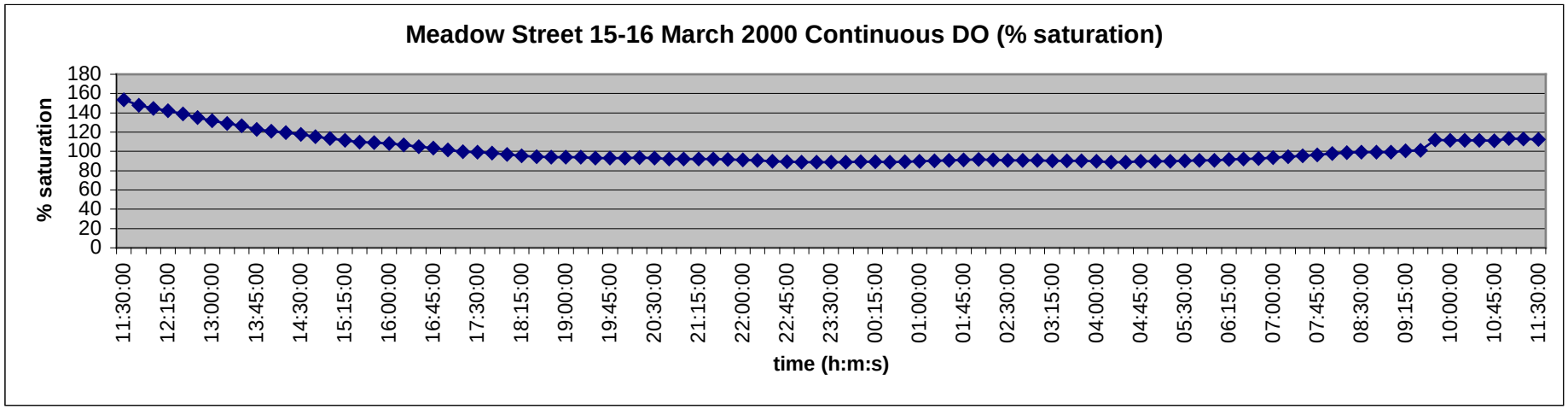


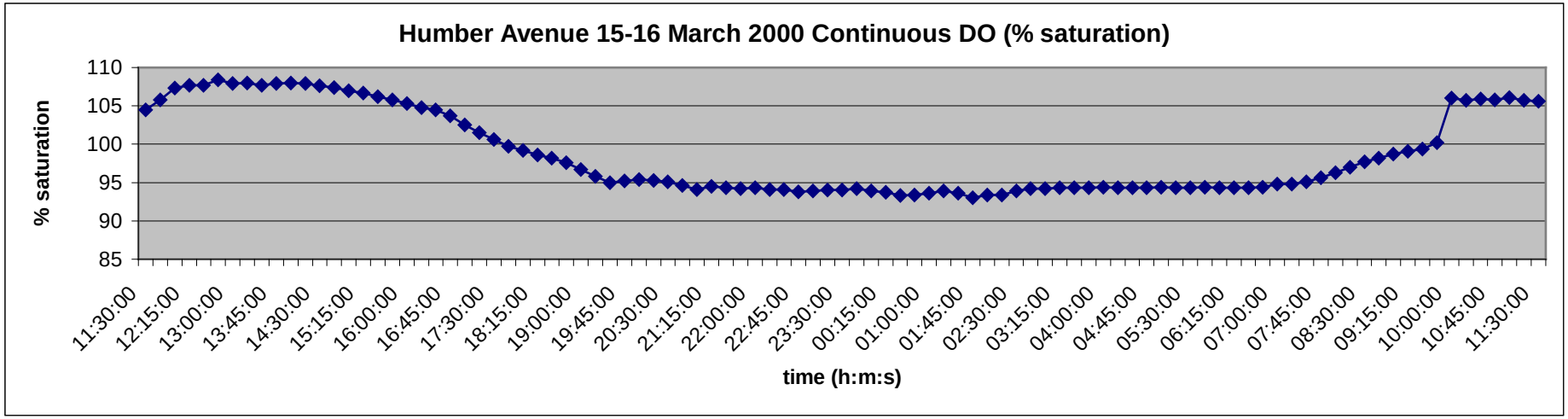
h) Nickel

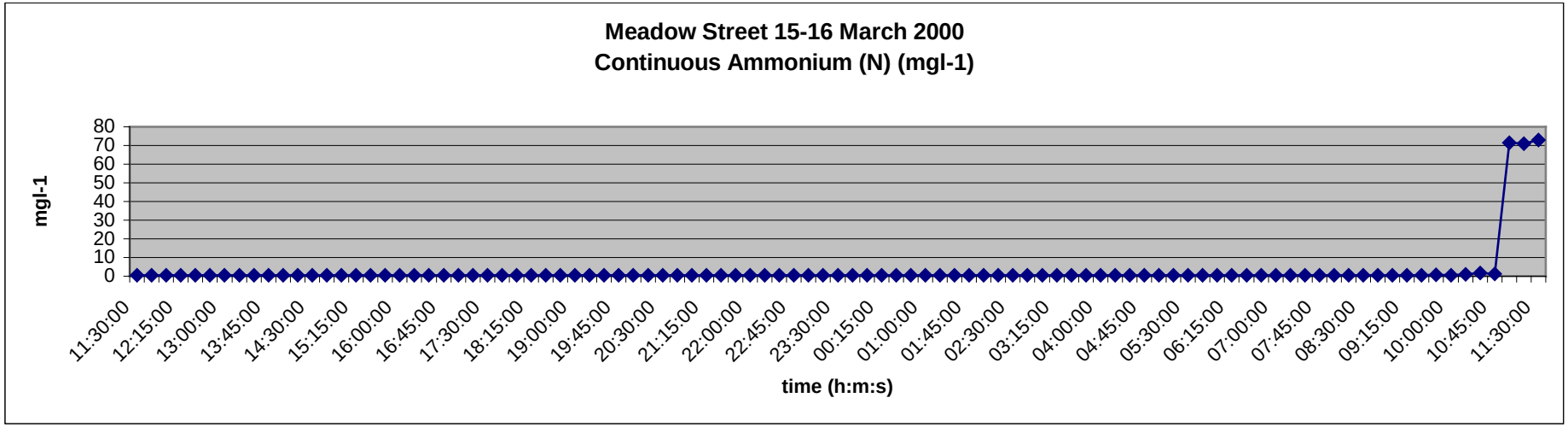

Humber Ave Nickel Auto 3 15-03-00
Nickel ugl-1
ugl-1
15
10
5
0
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
time (hours)

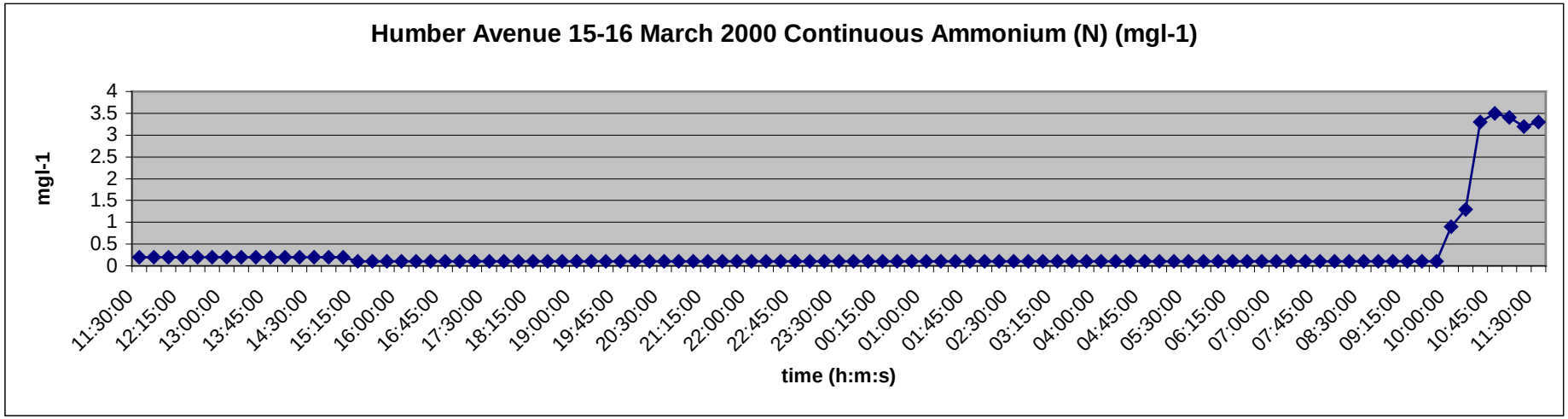
Dry period

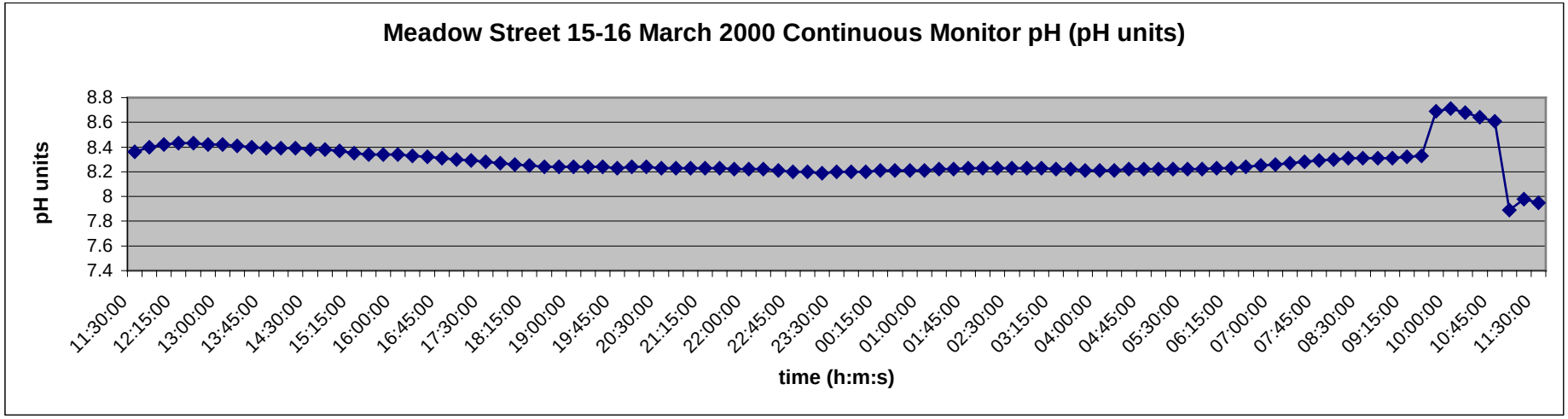
Auto 3 Continuous monitor 15 – 16 March 2000






Meadow Street 15-16 March 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
80
70
60
50
40
30
20
10
0
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
15:15:00
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
time (h:m:s)


Humber Avenue 15-16 March 2000 Continuous Ammonium (N) (mgl-1)
mgl-1
4
3.5
3
2.5
2
1.5
1
0.5
0
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
15:15:00
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
time (h:m:s)


Meadow Street 15-16 March 2000 Continuous Monitor pH (pH units)
pH units
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
15:15:00
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
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01:00:00
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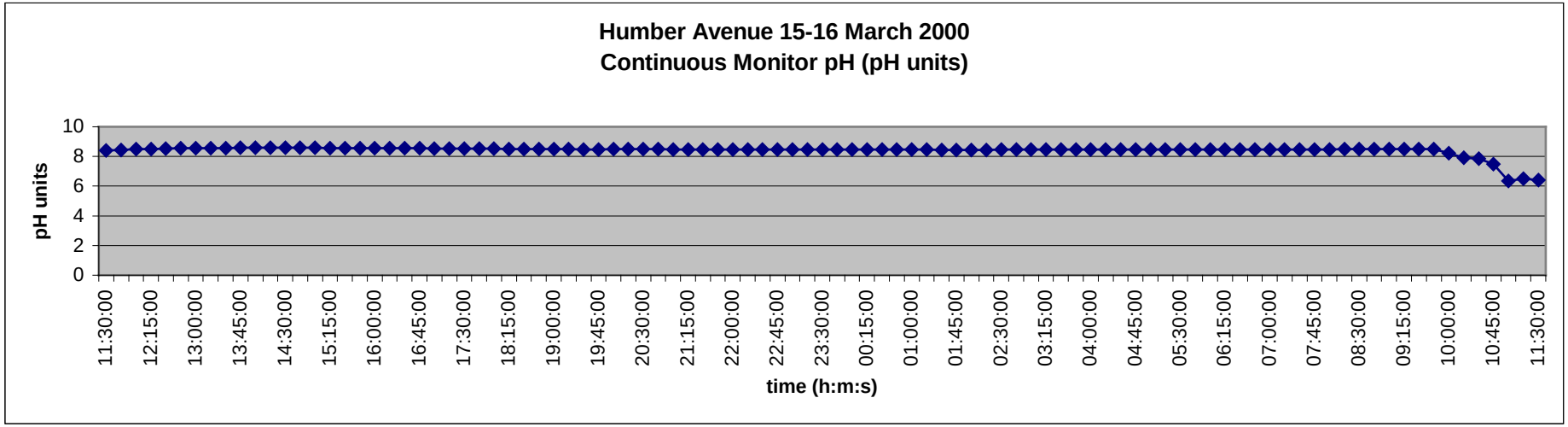
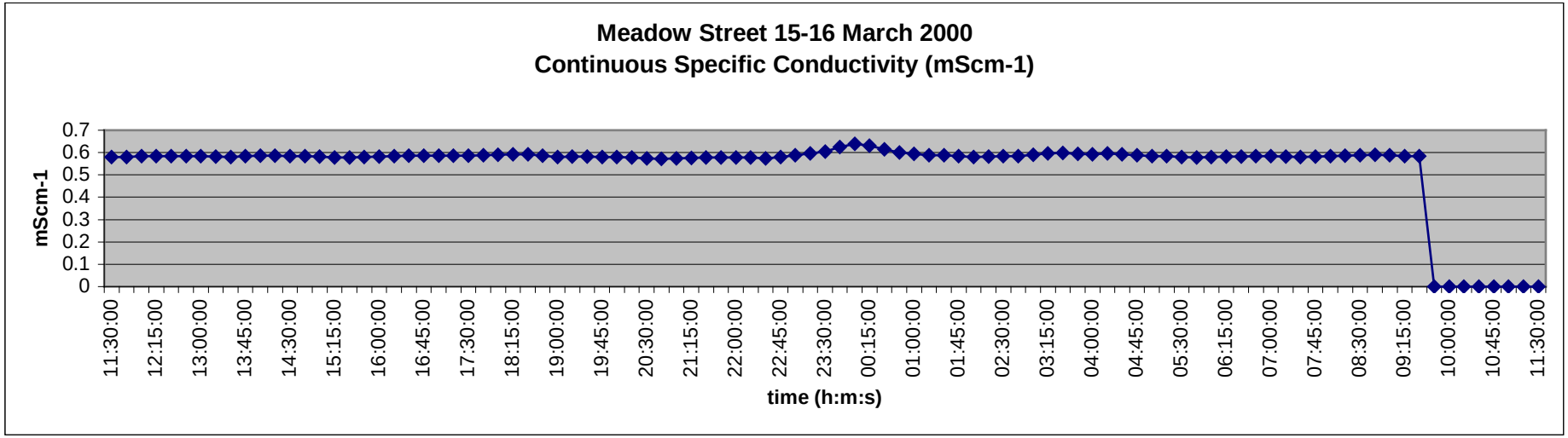
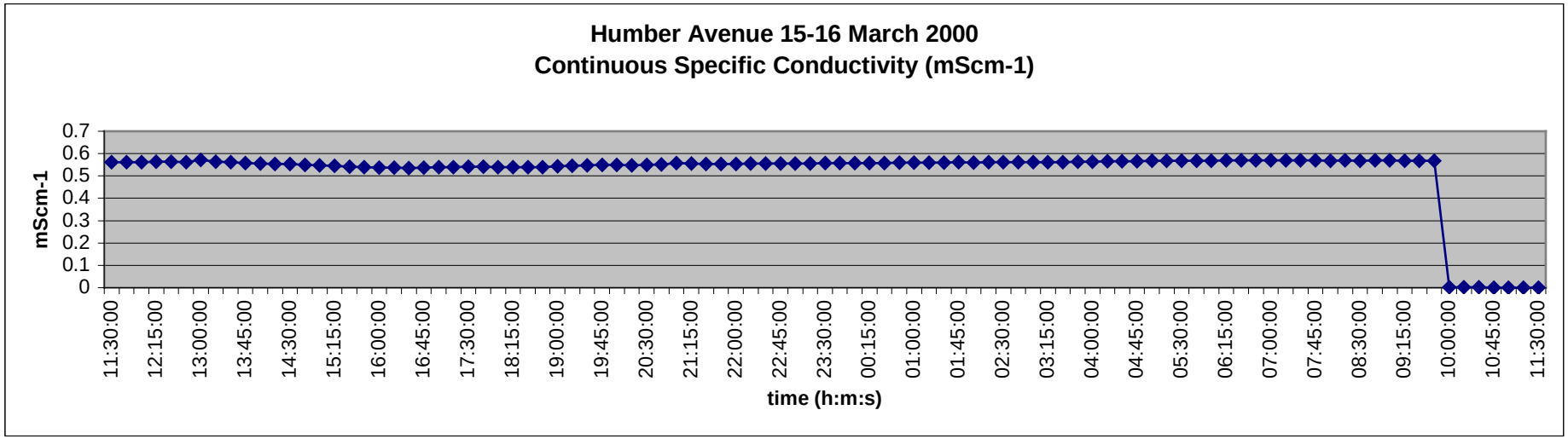
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
time (h:m:s)


Humber Avenue 15-16 March 2000
Continuous Monitor pH (pH units)
pH units
10
8
6
4
2
0
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
15:15:00
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
time (h:m:s)

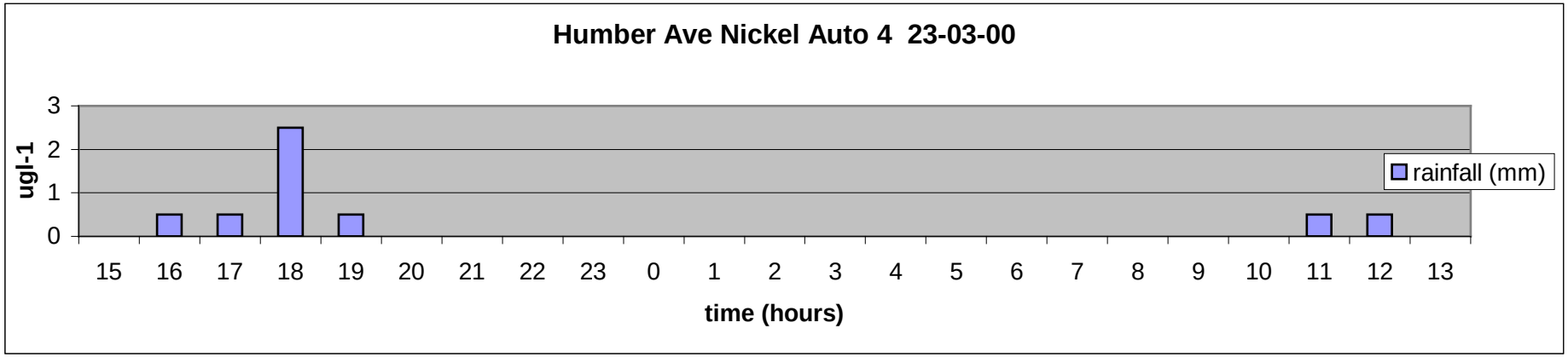

Meadow Street 15-16 March 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
15:15:00
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
time (h:m:s)

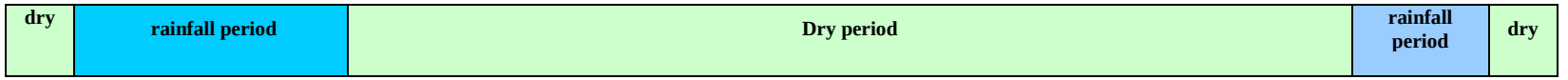

Humber Avenue 15-16 March 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
15:15:00
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
time (h:m:s)

Auto4 – no continuous monitor runs

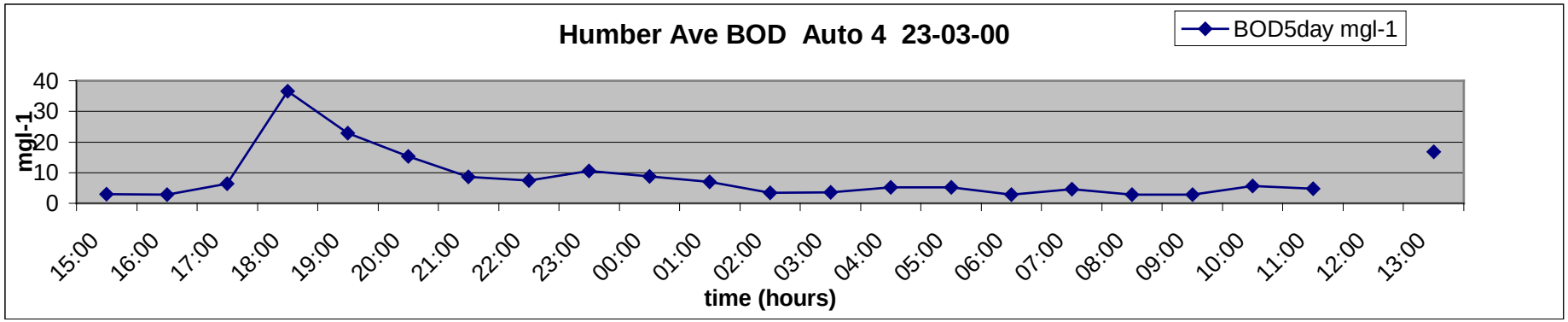
Auto 4 Humber Avenue 23-24 March 2000

a) Rainfall

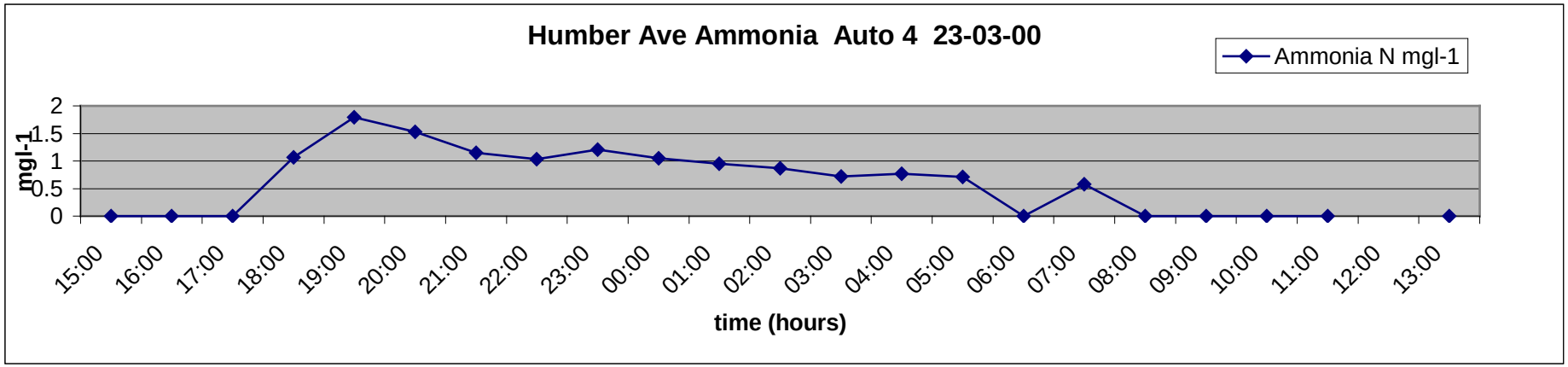


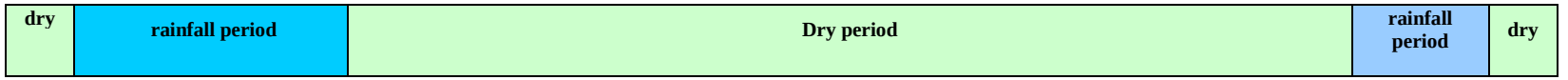


b) Biochemical Oxygen Demand BOD

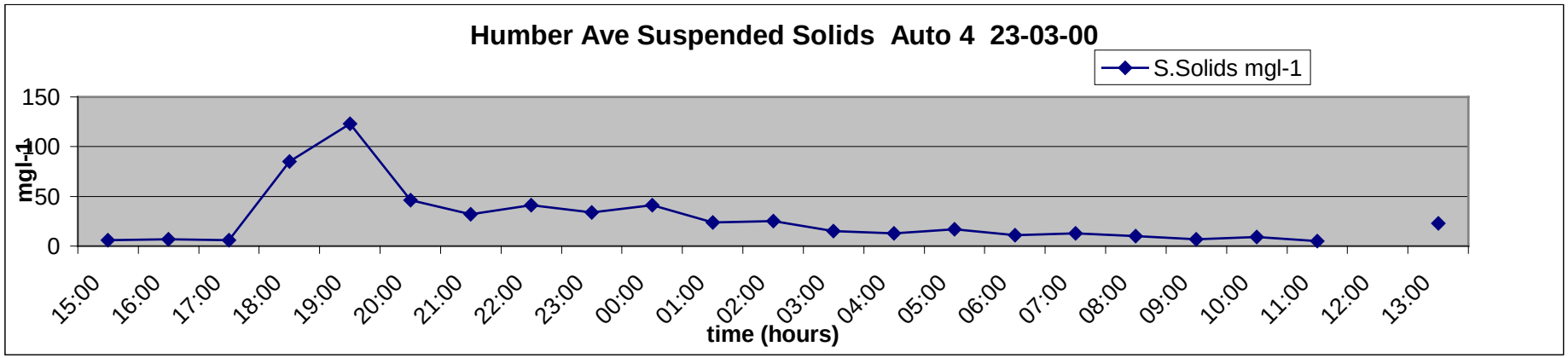


c) Ammonia

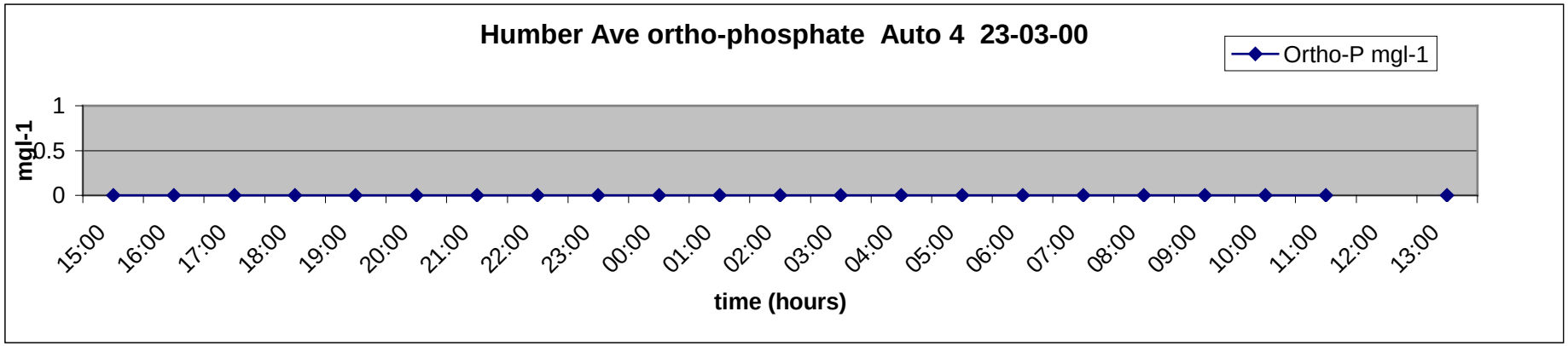


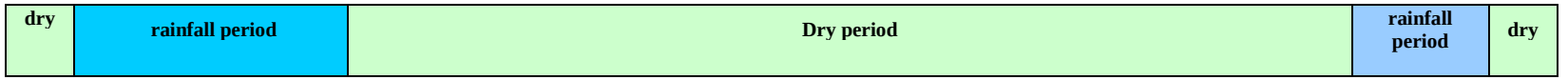


d) Suspended Solids

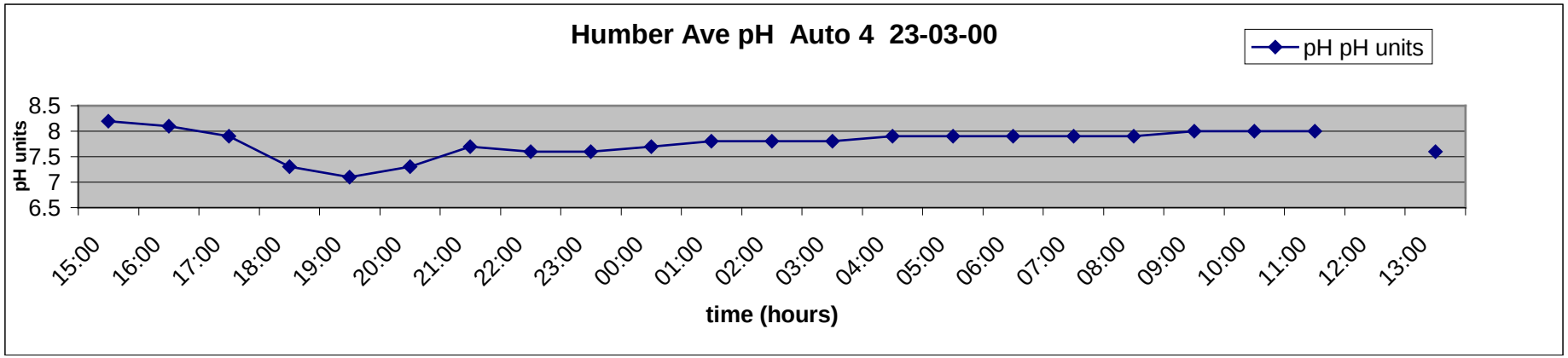


e) Ortho-phosphate

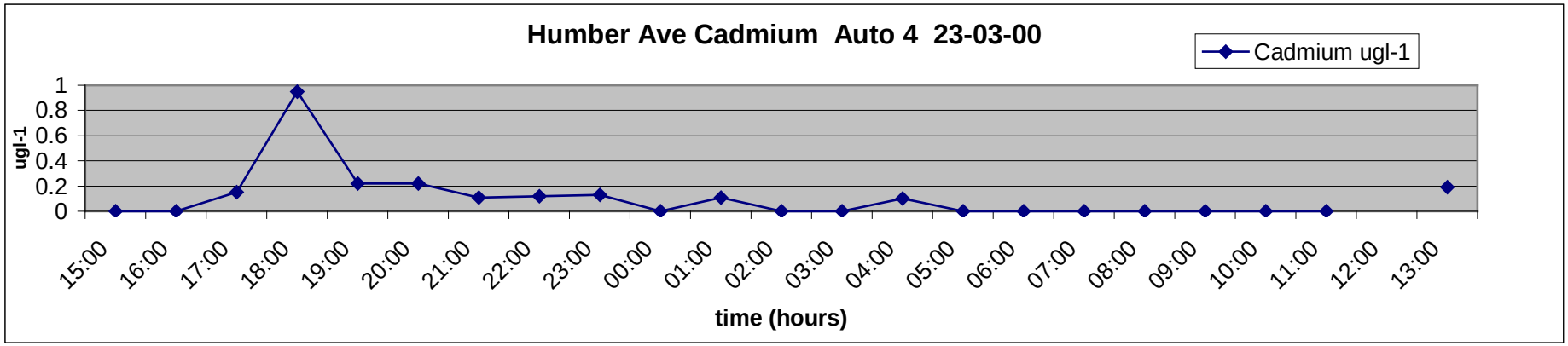


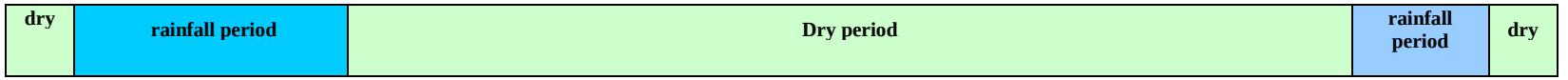


f) pH

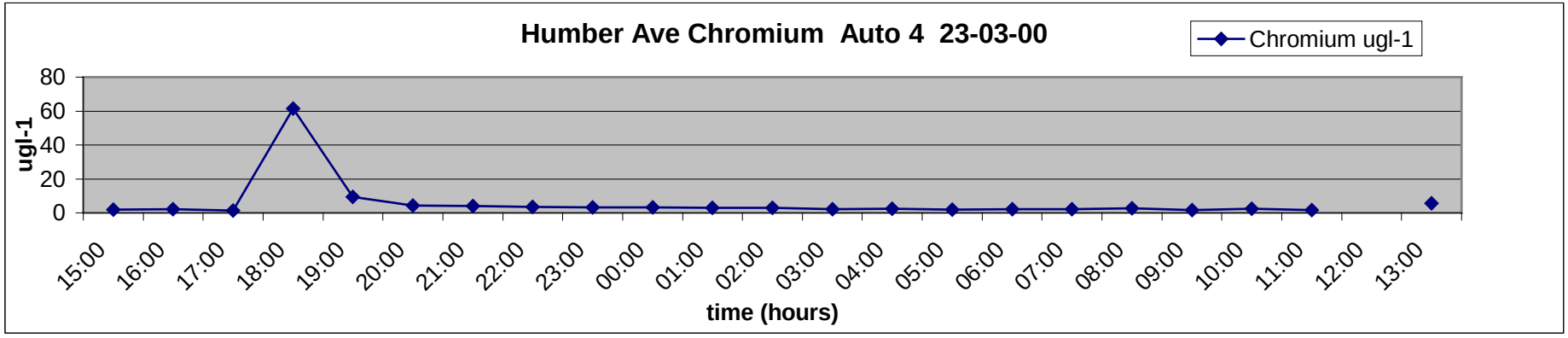


g) Cadmium

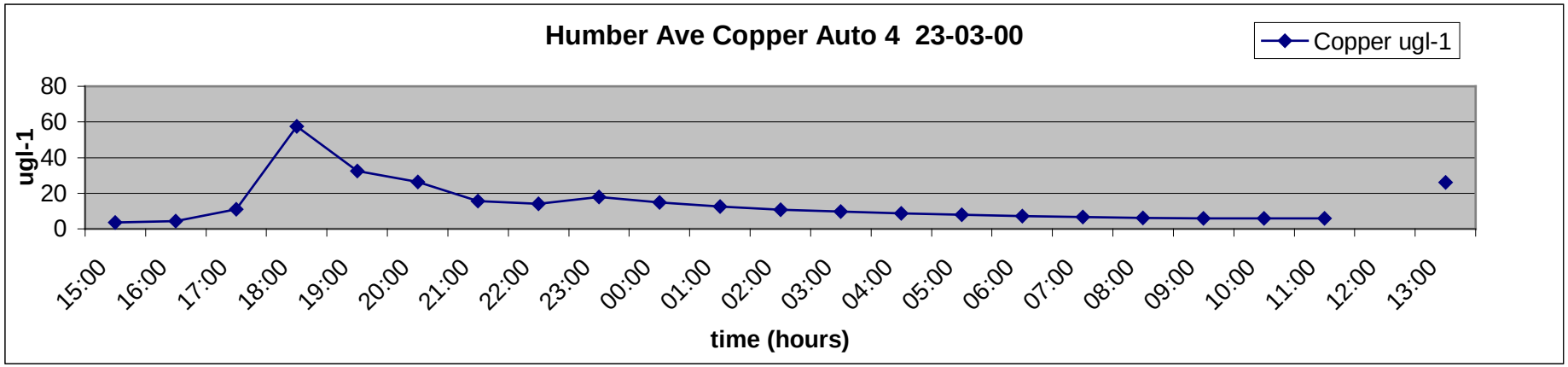


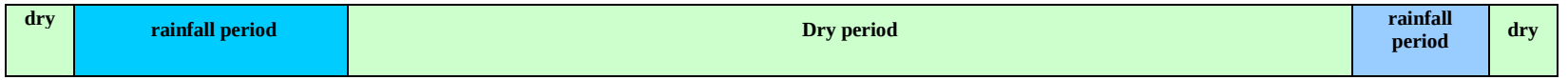


h) Chromium

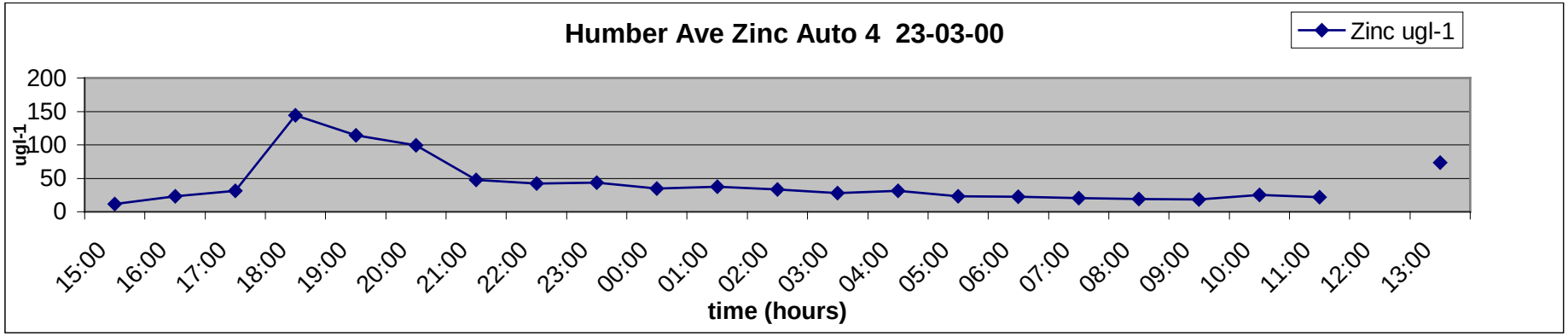


i) Copper

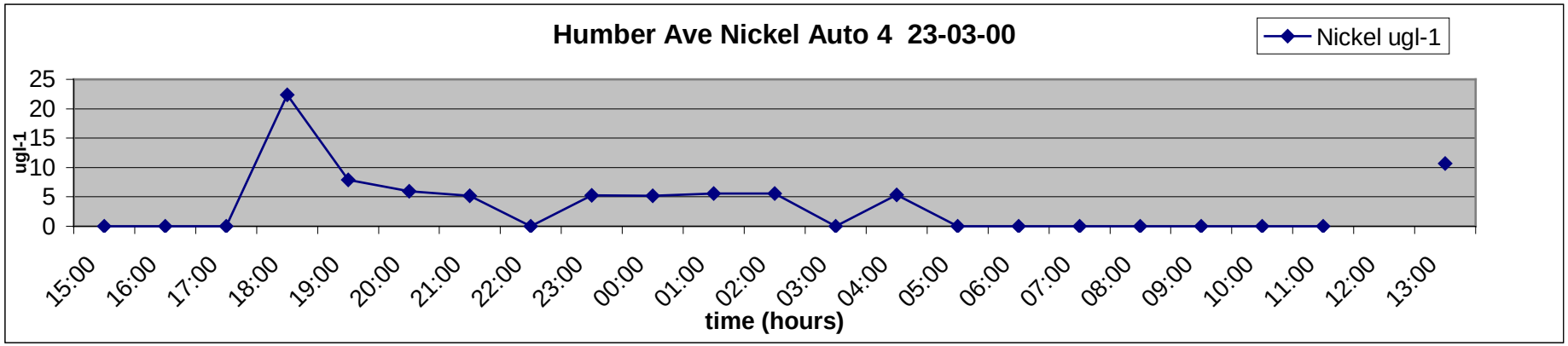




j) Zinc

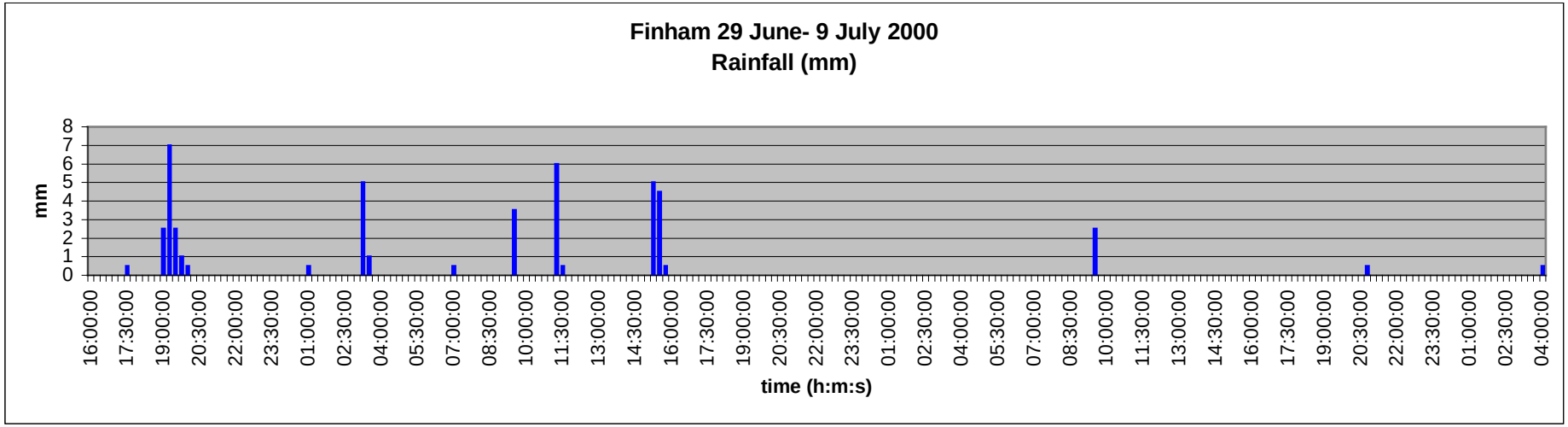


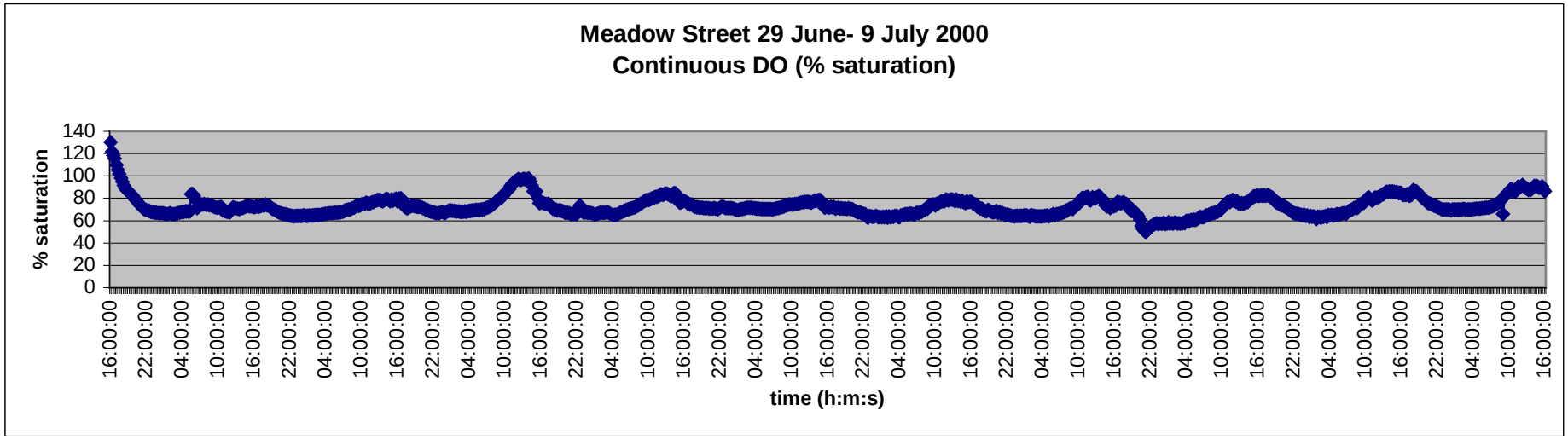
k) Nickel

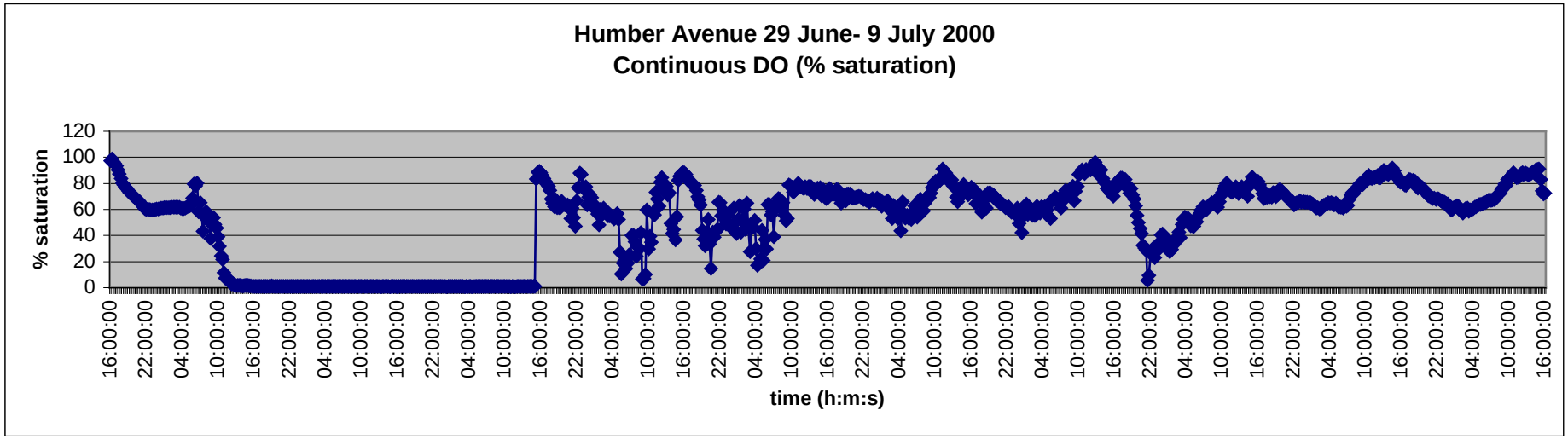


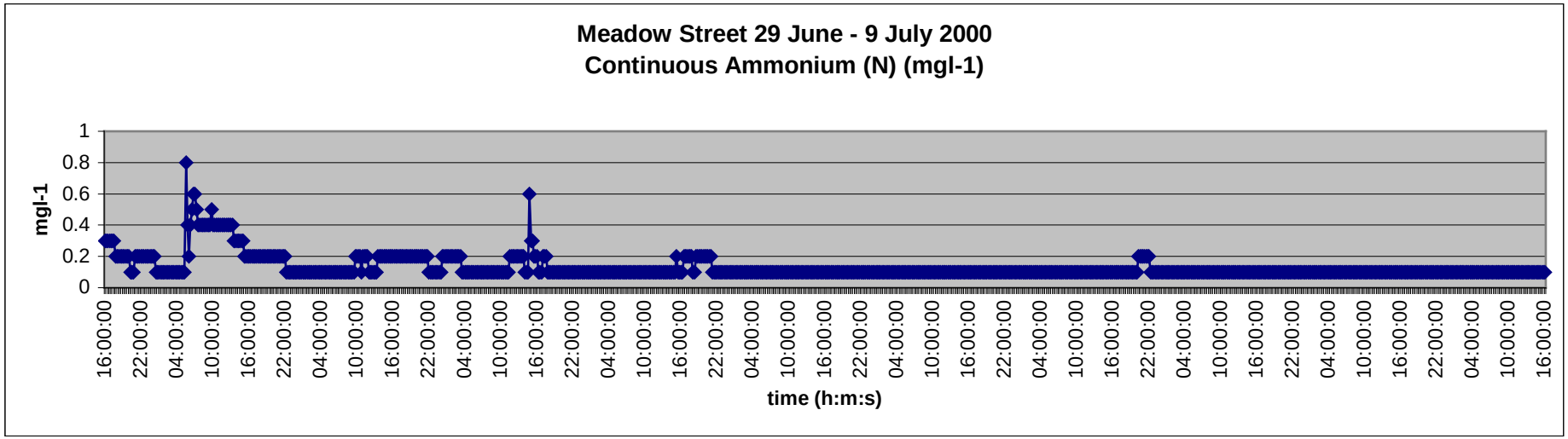
dry	rainfall period	Dry period	rainfall period	dry

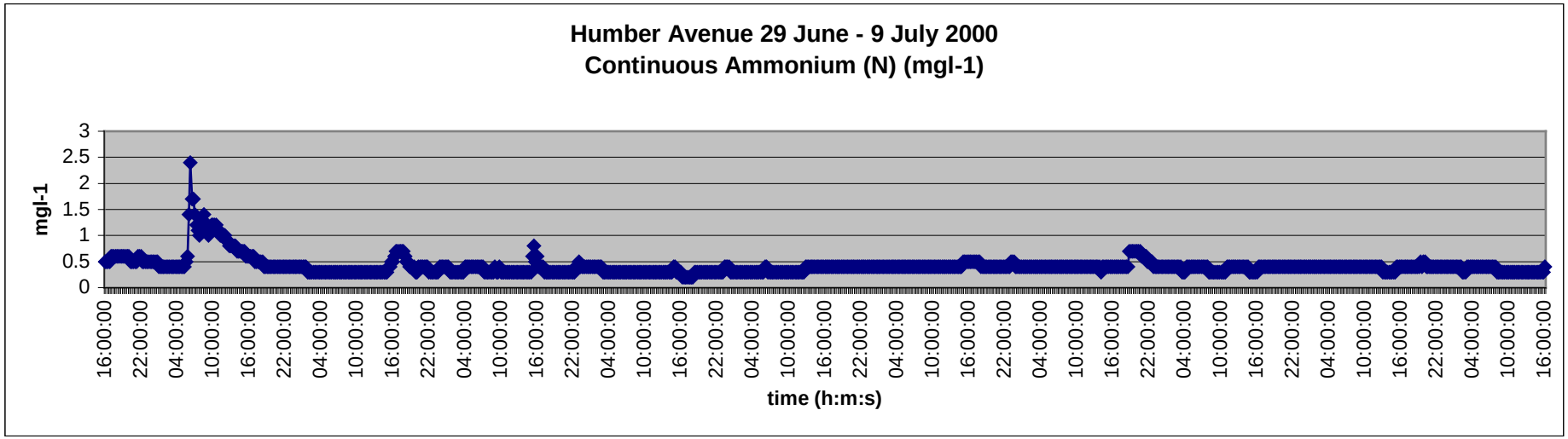
Run c) 29 June 2000

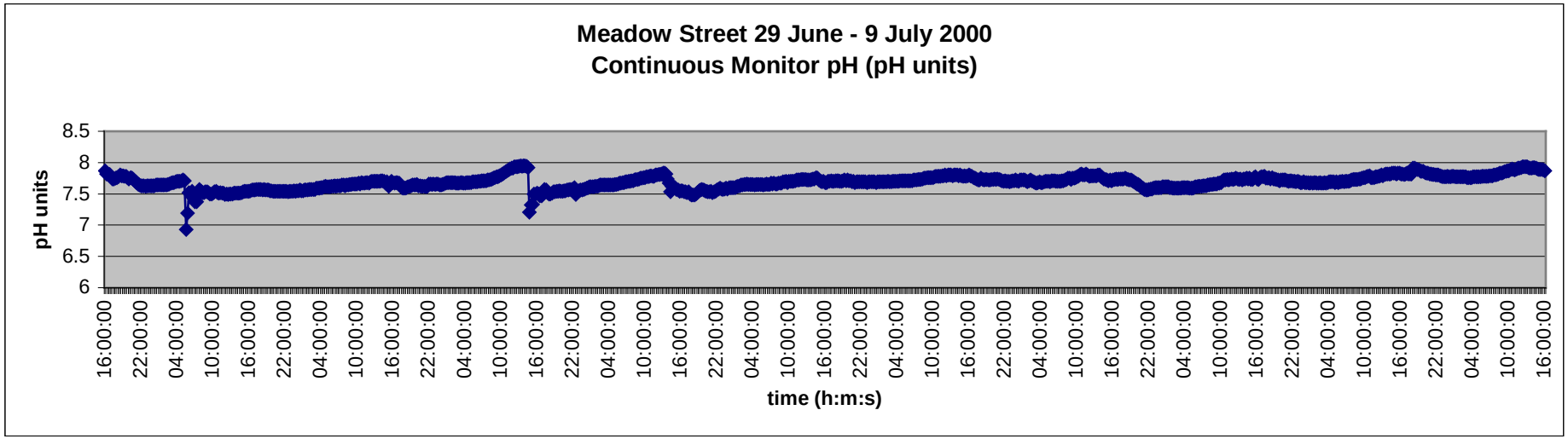


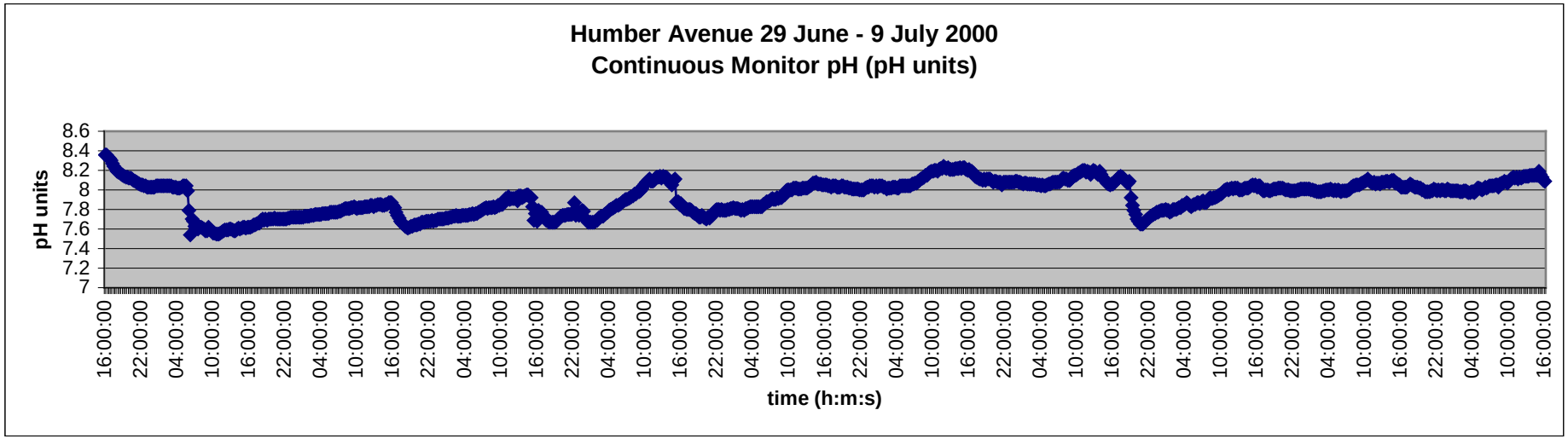

Meadow Street 29 June- 9 July 2000
Continuous DO (% saturation)
% saturation
140
120
100
80
60
40
20
0
16:00:00
22:00:00
04:00:00
10:00:00
time (h:m:s)

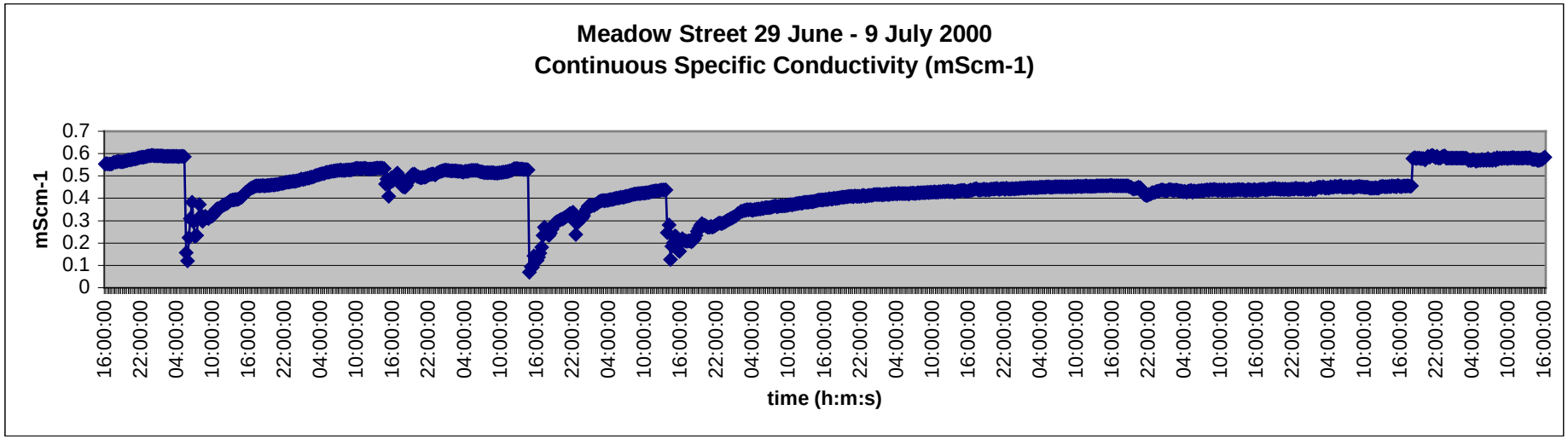

Humber Avenue 29 June- 9 July 2000
Continuous DO (% saturation)
% saturation
120
100
80
60
40
20
0
16:00:00
22:00:00
04:00:00
10:00:00
time (h:m:s)

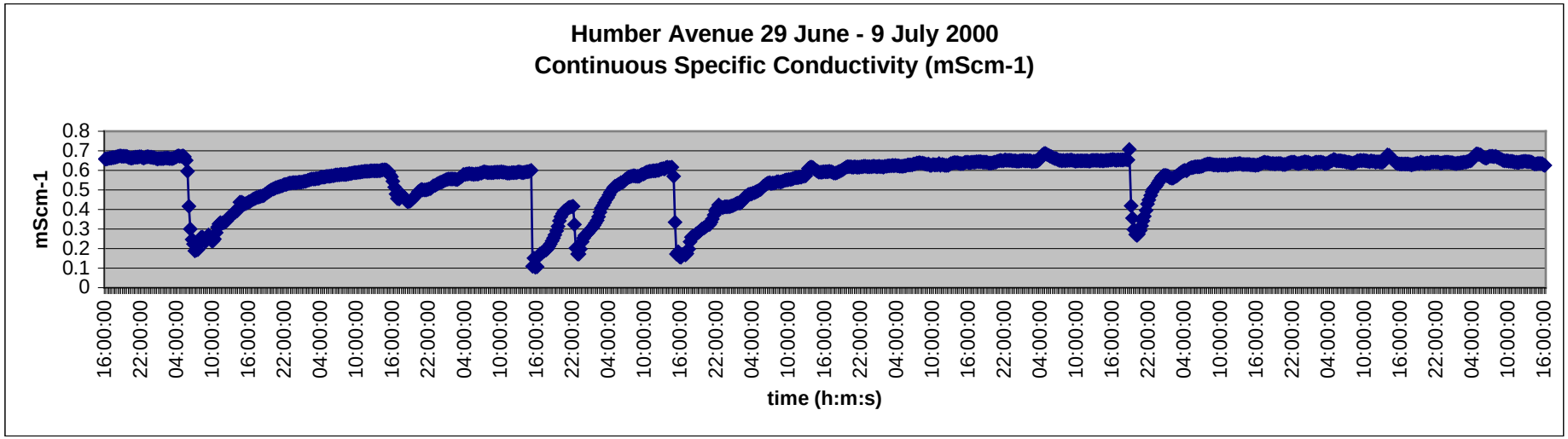

Meadow Street 29 June - 9 July 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
1
0.8
0.6
0.4
0.2
0
16:00:00
22:00:00
04:00:00
10:00:00
time (h:m:s)

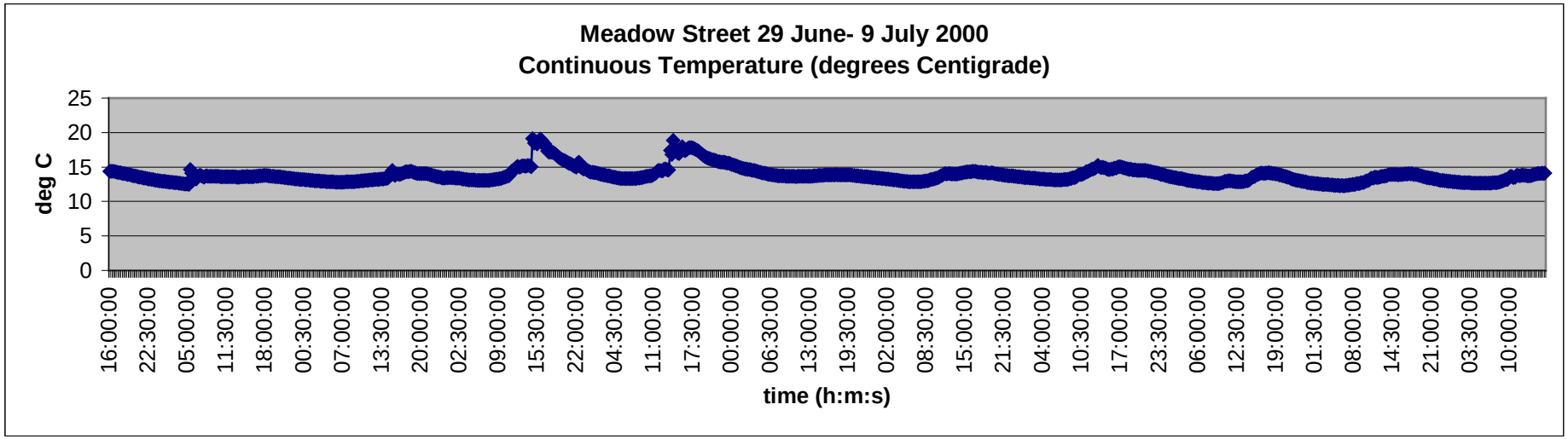

Humber Avenue 29 June - 9 July 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
3
2.5
2
1.5
1
0.5
0
16:00:00
22:00:00
04:00:00
10:00:00
time (h:m:s)

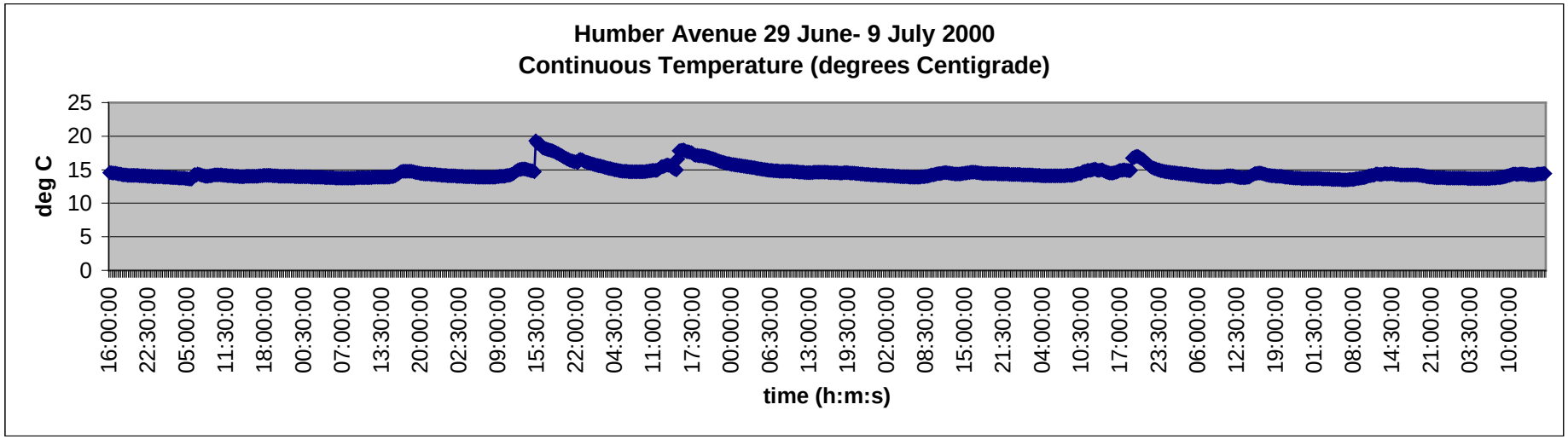

Meadow Street 29 June - 9 July 2000
Continuous Monitor pH (pH units)
pH units
8.5
8
7.5
7
6.5
6
16:00:00
22:00:00
04:00:00
10:00:00
time (h:m:s)


Humber Avenue 29 June - 9 July 2000
Continuous Monitor pH (pH units)
pH units
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
16:00:00
22:00:00
04:00:00
10:00:00
time (h:m:s)


Meadow Street 29 June - 9 July 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
16:00:00
22:00:00
04:00:00
10:00:00
time (h:m:s)

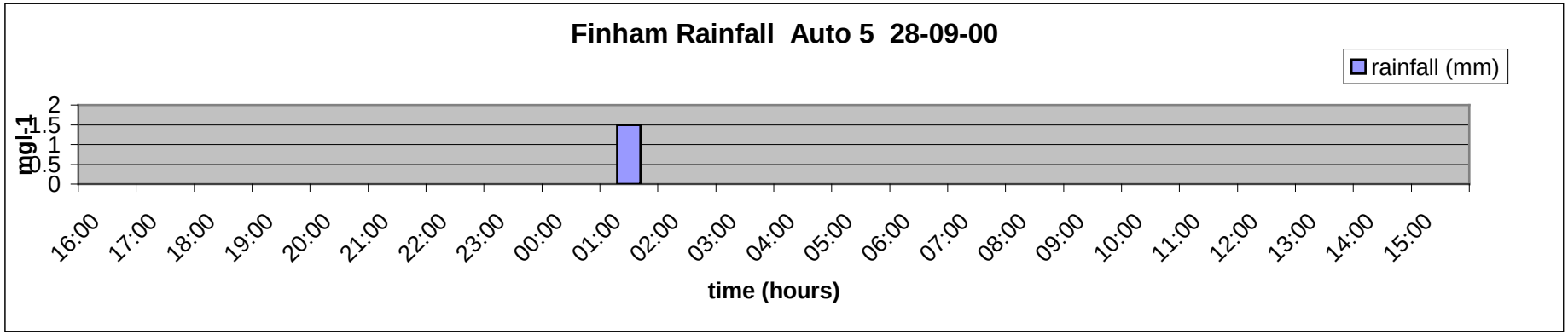

Humber Avenue 29 June - 9 July 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
16:00:00
22:00:00
04:00:00
10:00:00
time (h:m:s)

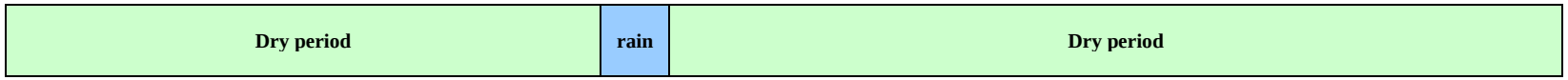

Meadow Street 29 June- 9 July 2000
Continuous Temperature (degrees Centigrade)
deg C
25
20
15
10
5
0
16:00:00
22:30:00
05:00:00
11:30:00
18:00:00
00:30:00
07:00:00
13:30:00
20:00:00
02:30:00
09:00:00
15:30:00
22:00:00
04:30:00
11:00:00
17:30:00
00:00:00
06:30:00
13:00:00
19:30:00
02:00:00
08:30:00
15:00:00
21:30:00
04:00:00
10:30:00
17:00:00
23:30:00
06:00:00
12:30:00
19:00:00
01:30:00
08:00:00
14:30:00
21:00:00
03:30:00
10:00:00
time (h:m:s)


Humber Avenue 29 June- 9 July 2000
Continuous Temperature (degrees Centigrade)
deg C
25
20
15
10
5
0
16:00:00
22:30:00
05:00:00
11:30:00
18:00:00
00:30:00
07:00:00
13:30:00
20:00:00
02:30:00
09:00:00
15:30:00
22:00:00
04:30:00
11:00:00
17:30:00
00:00:00
06:30:00
13:00:00
19:30:00
02:00:00
08:30:00
15:00:00
21:30:00
04:00:00
10:30:00
17:00:00
23:30:00
06:00:00
12:30:00
19:00:00
01:30:00
08:00:00
14:30:00
21:00:00
03:30:00
10:00:00
time (h:m:s)

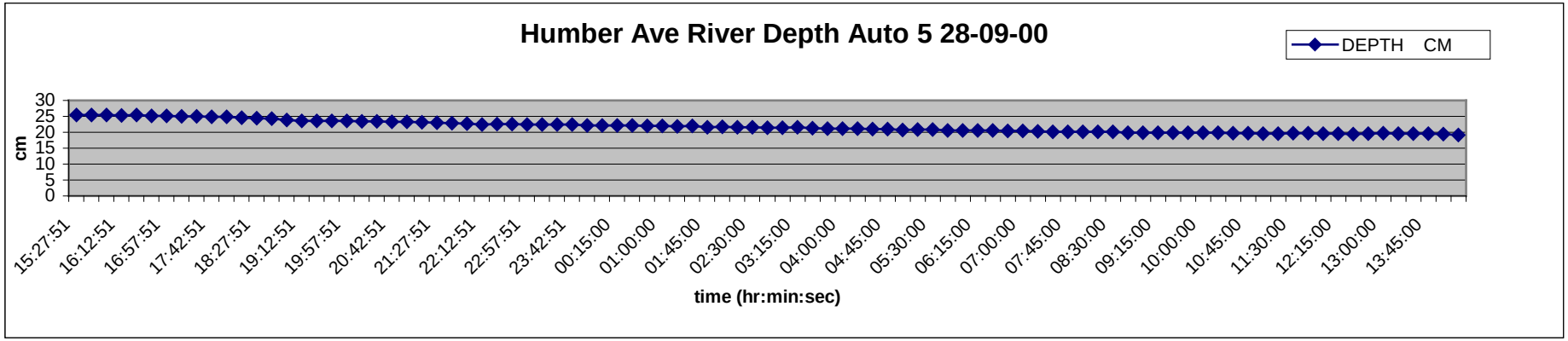
Auto 5 Humber Avenue 28-29 September 2000 - no rainfall locally. No metals determination

a) Rainfall

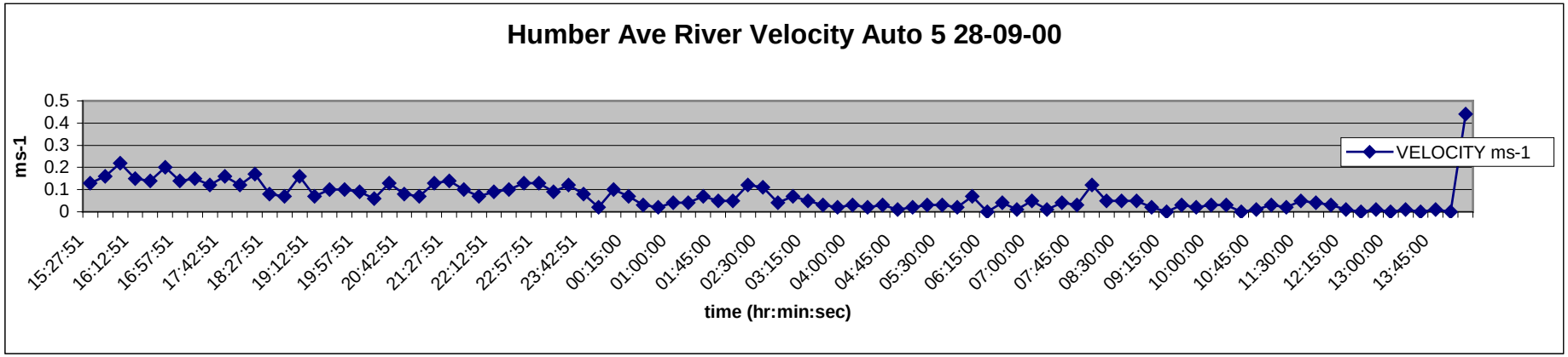


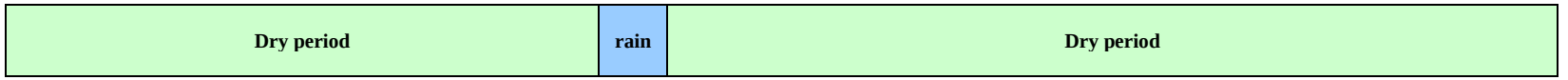


ai) River depth

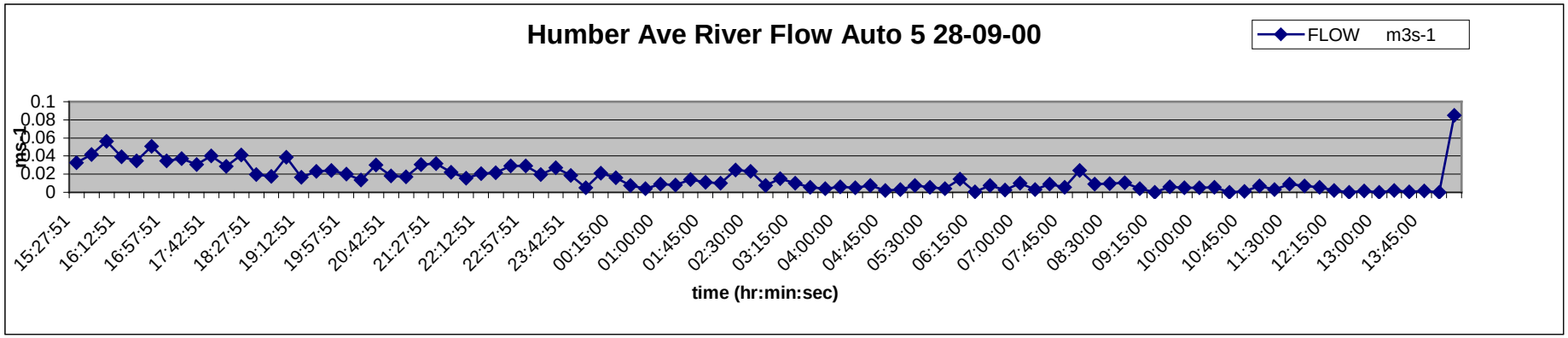


aii) River Velocity

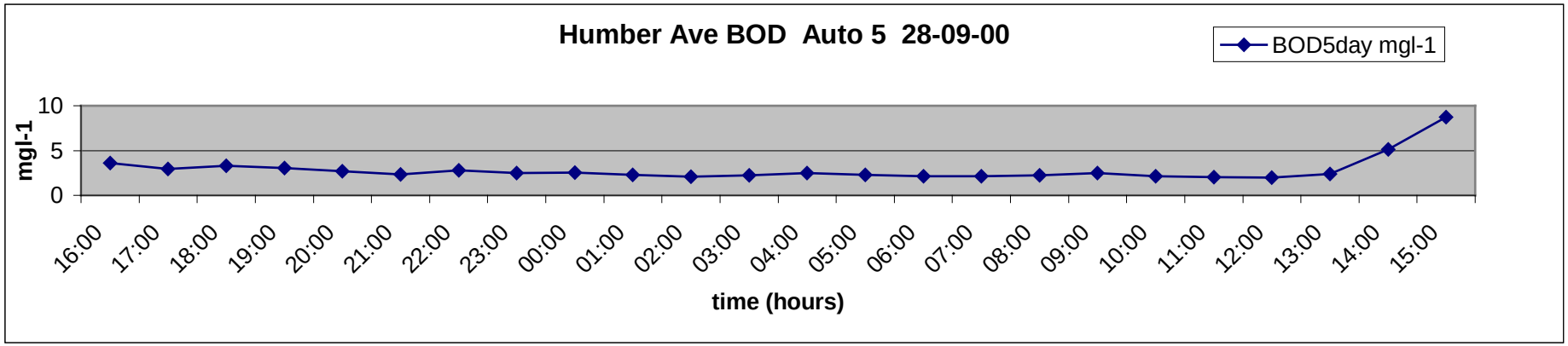


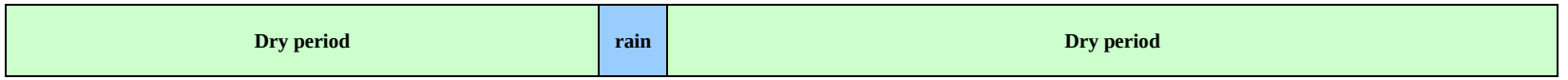


aiii) River Flow

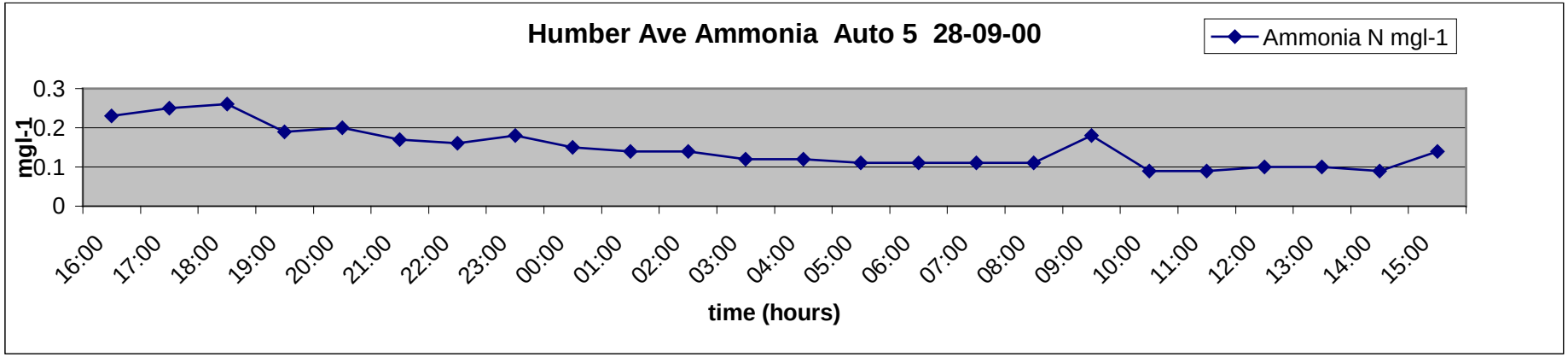


b) Biochemical Oxygen Demand



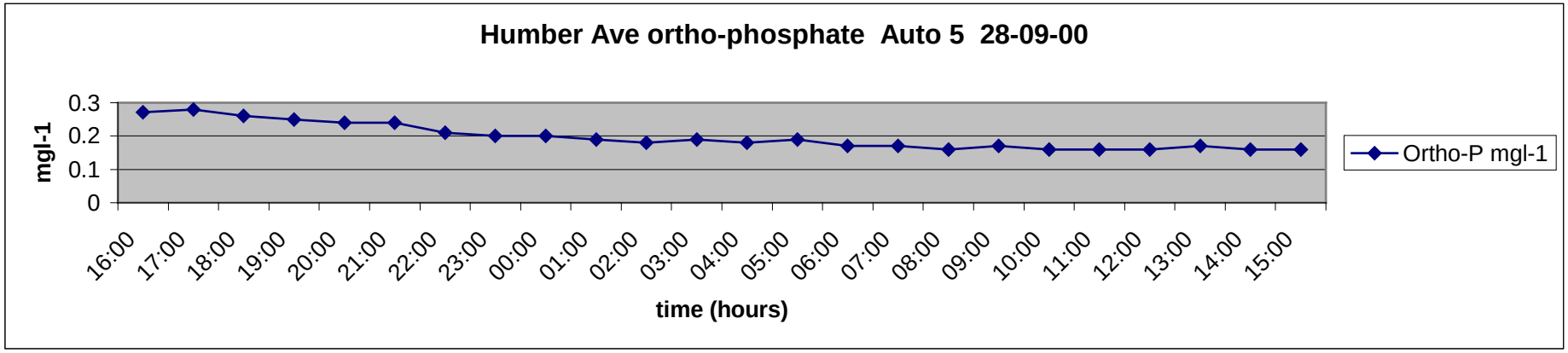


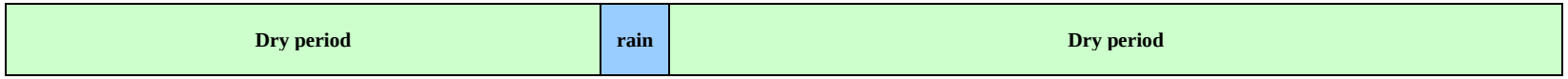
c) Ammonia



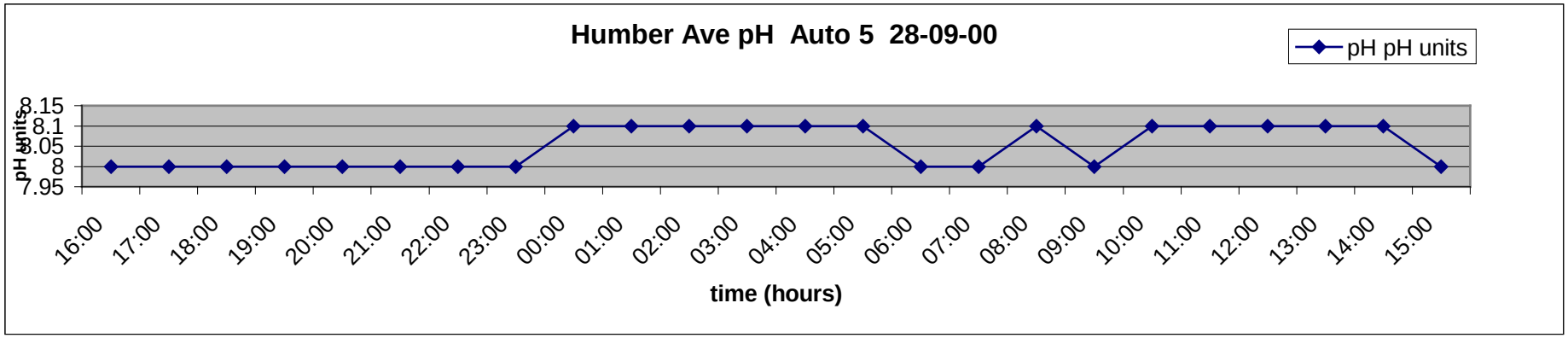
d) Suspended Solids – no data collected

e) Ortho-phosphate

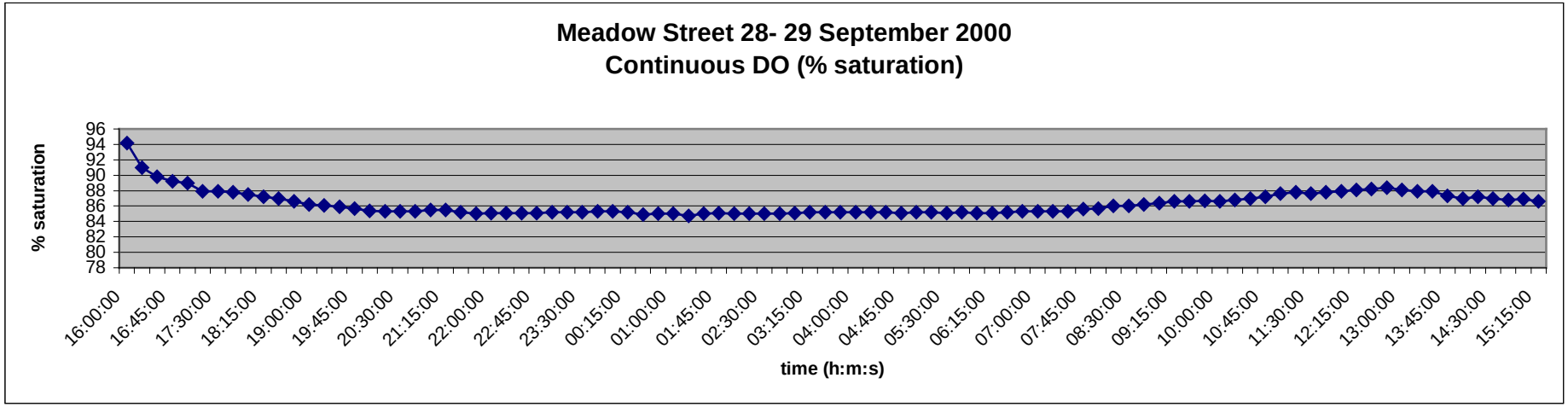


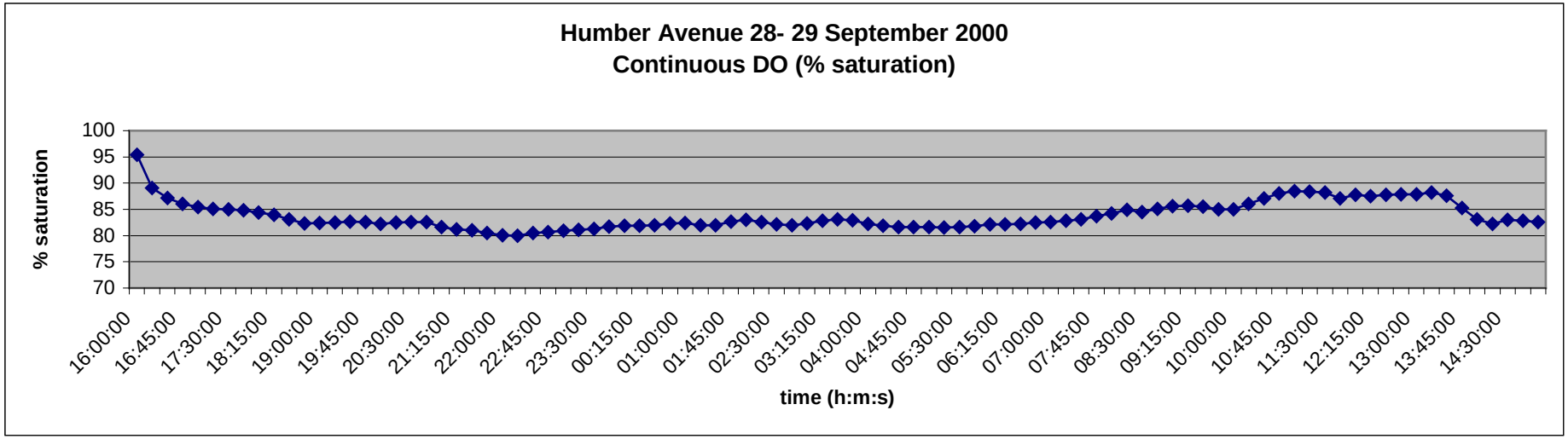


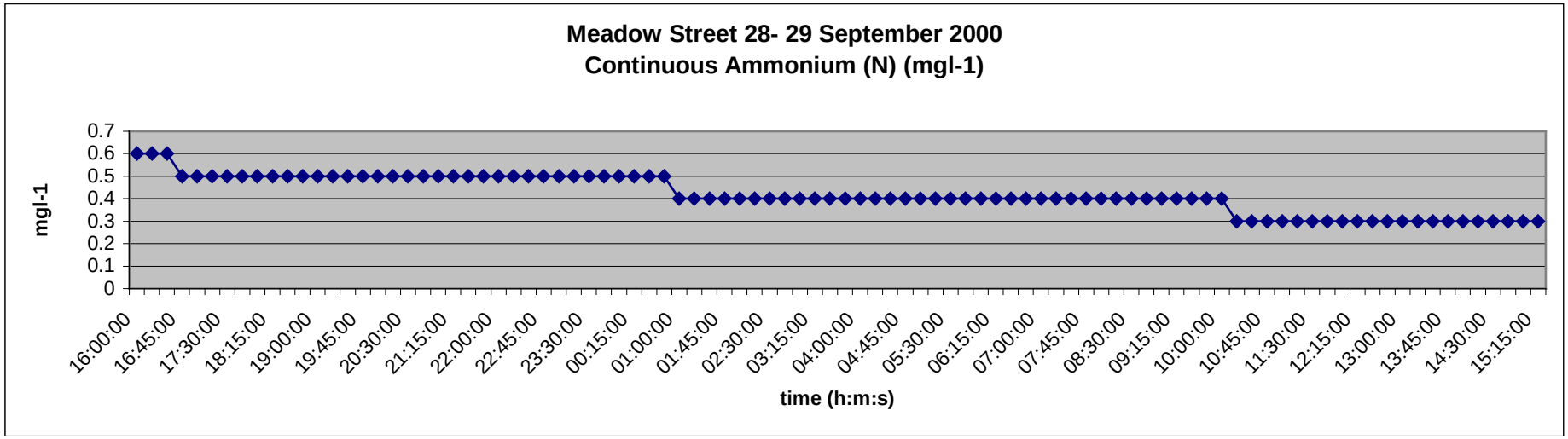
f) pH

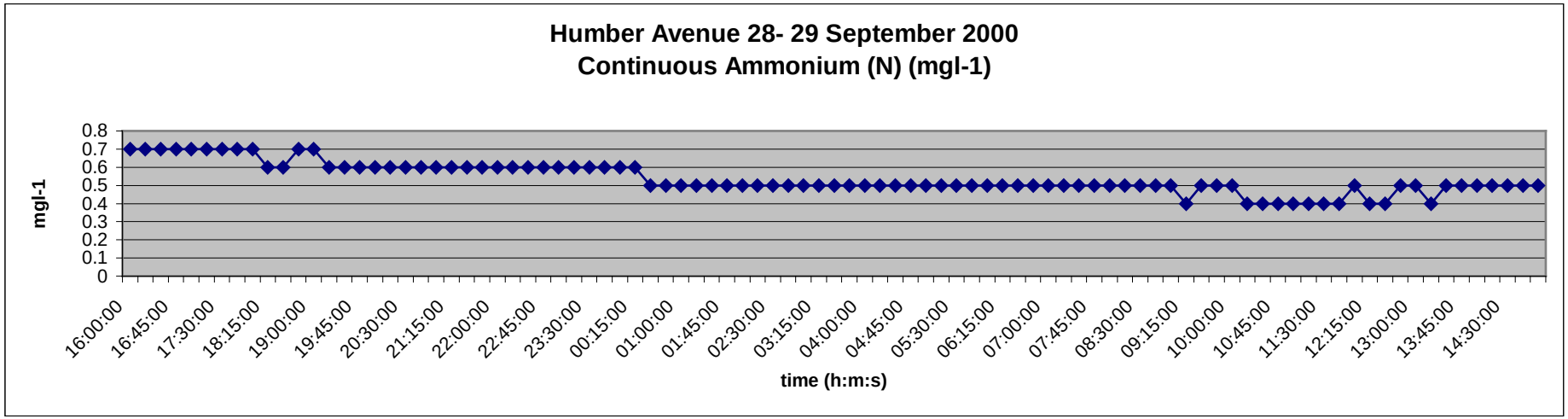


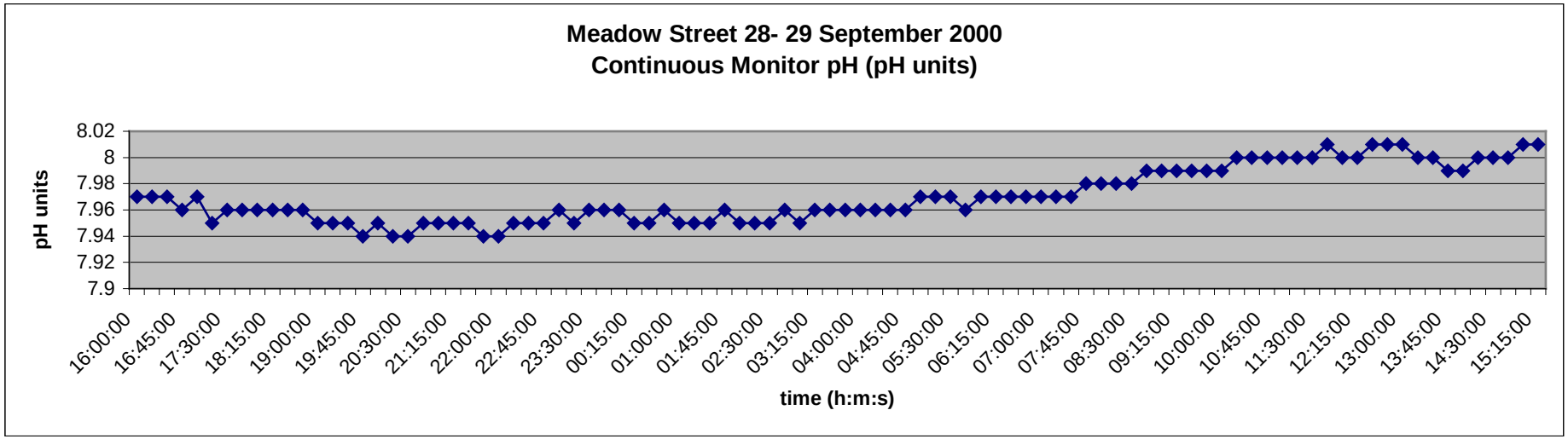
Auto5 Continuous monitors

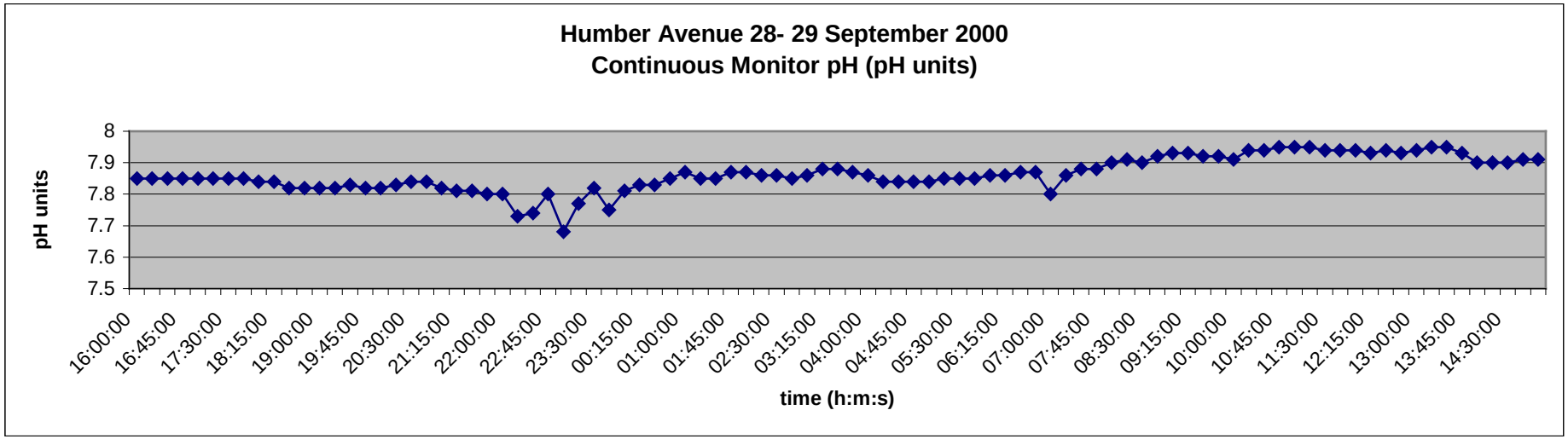


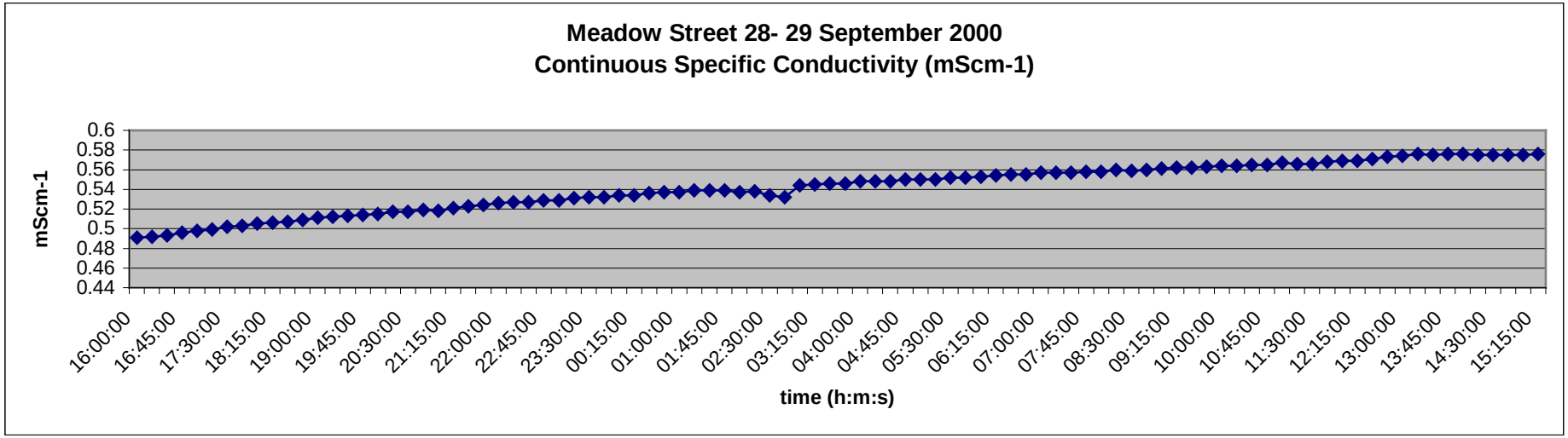


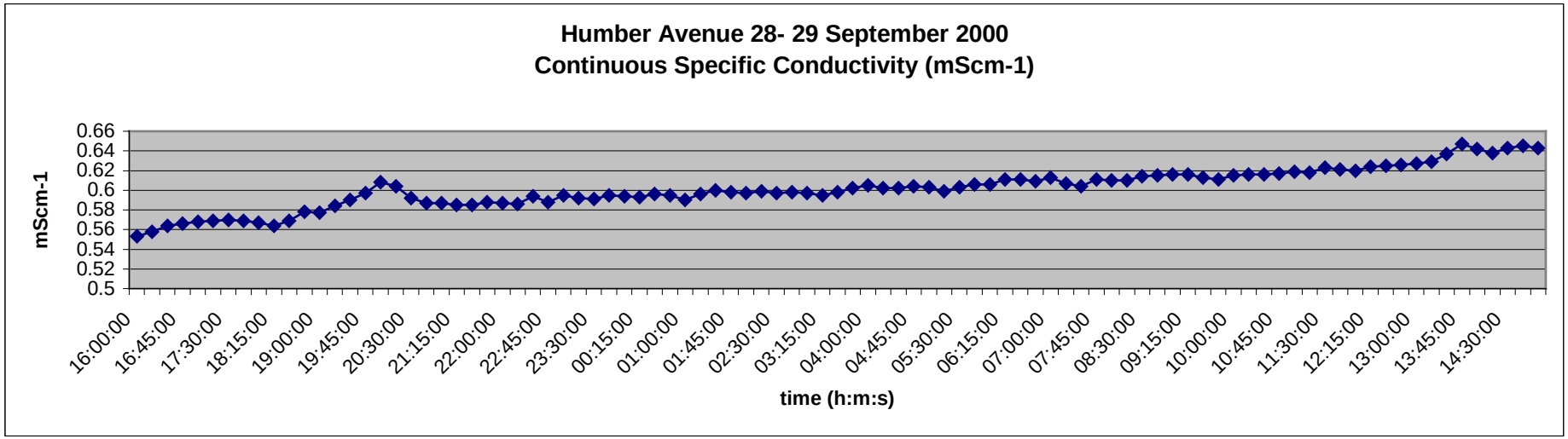

Meadow Street 28- 29 September 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
15:15:00
time (h:m:s)


Humber Avenue 28- 29 September 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
time (h:m:s)

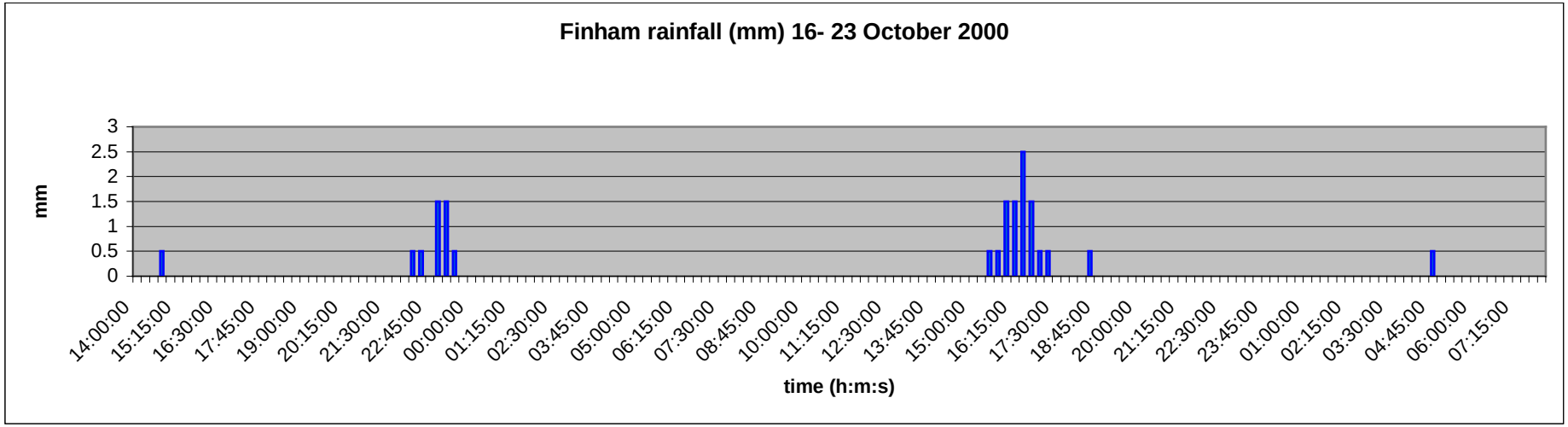

Meadow Street 28- 29 September 2000
Continuous Monitor pH (pH units)
pH units
8.02
8
7.98
7.96
7.94
7.92
7.9
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
15:15:00
time (h:m:s)

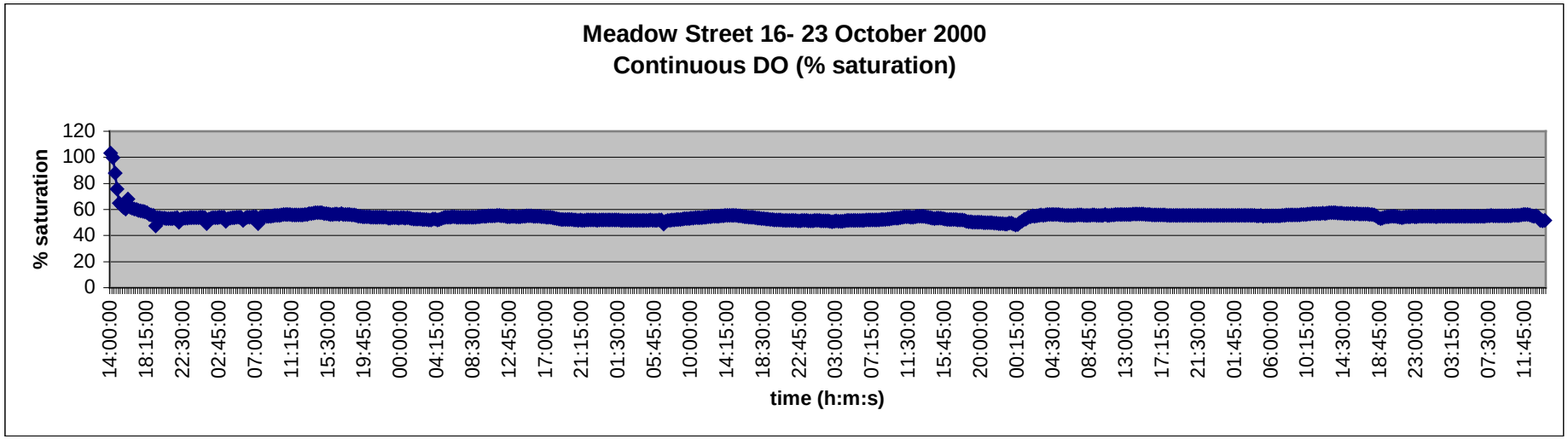

Humber Avenue 28- 29 September 2000
Continuous Monitor pH (pH units)
pH units
8
7.9
7.8
7.7
7.6
7.5
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
time (h:m:s)

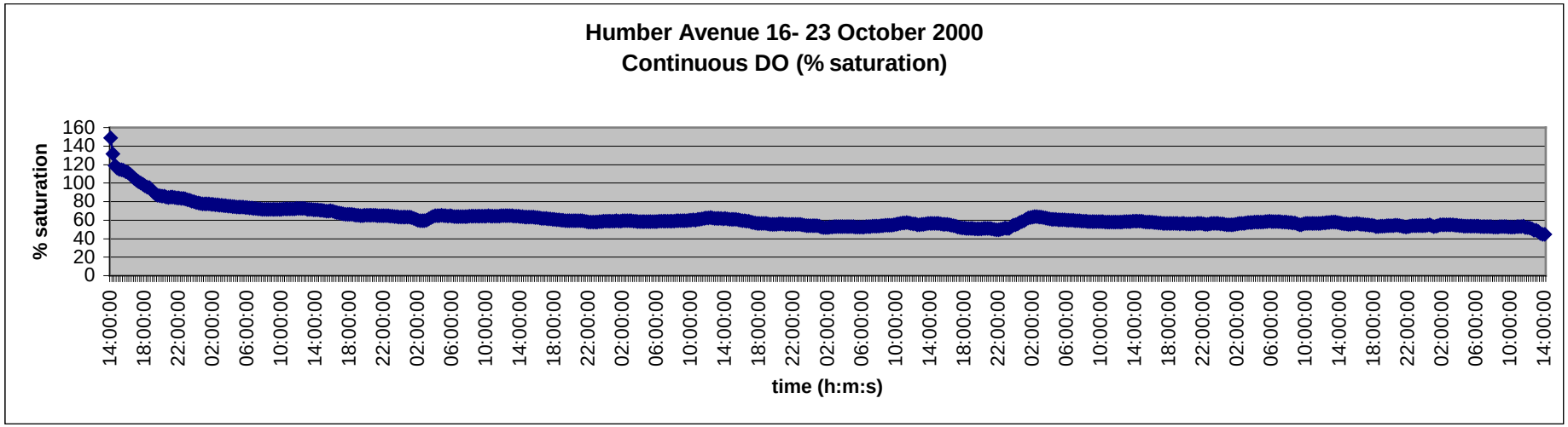

Meadow Street 28- 29 September 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
15:15:00
time (h:m:s)

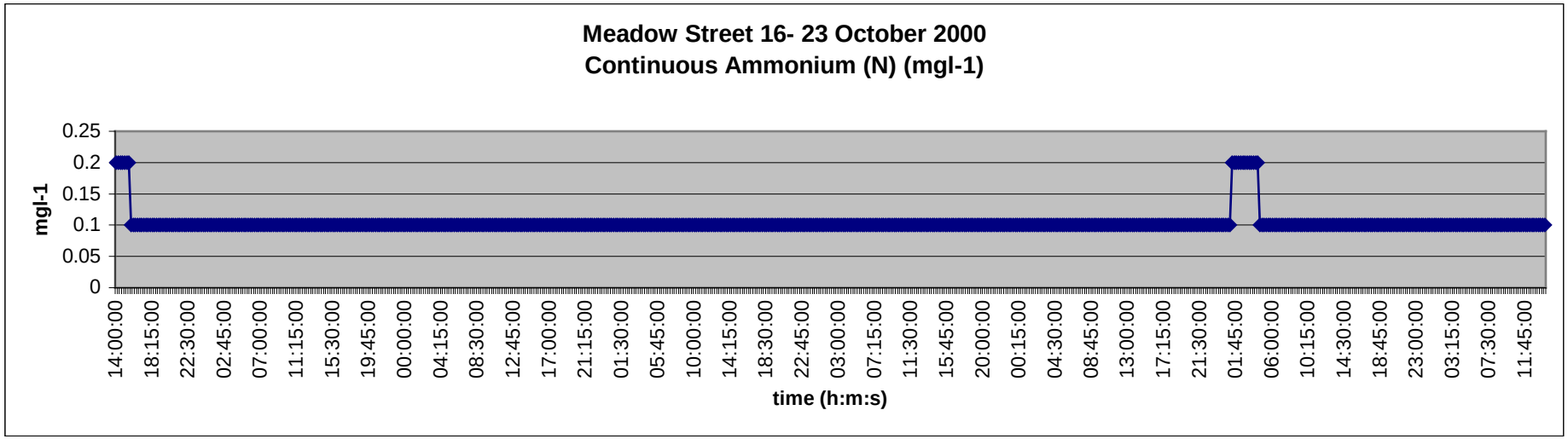

Humber Avenue 28- 29 September 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
16:00:00
16:45:00
17:30:00
18:15:00
19:00:00
19:45:00
20:30:00
21:15:00
22:00:00
22:45:00
23:30:00
00:15:00
01:00:00
01:45:00
02:30:00
03:15:00
04:00:00
04:45:00
05:30:00
06:15:00
07:00:00
07:45:00
08:30:00
09:15:00
10:00:00
10:45:00
11:30:00
12:15:00
13:00:00
13:45:00
14:30:00
time (h:m:s)

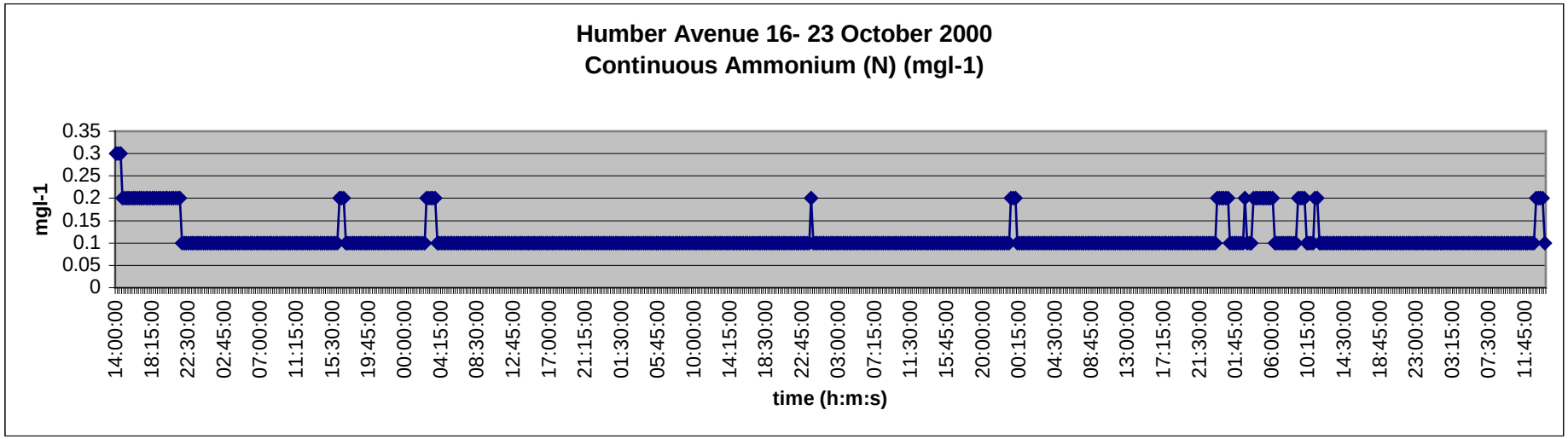
Continuous monitor run e) 16- 23 October 2000

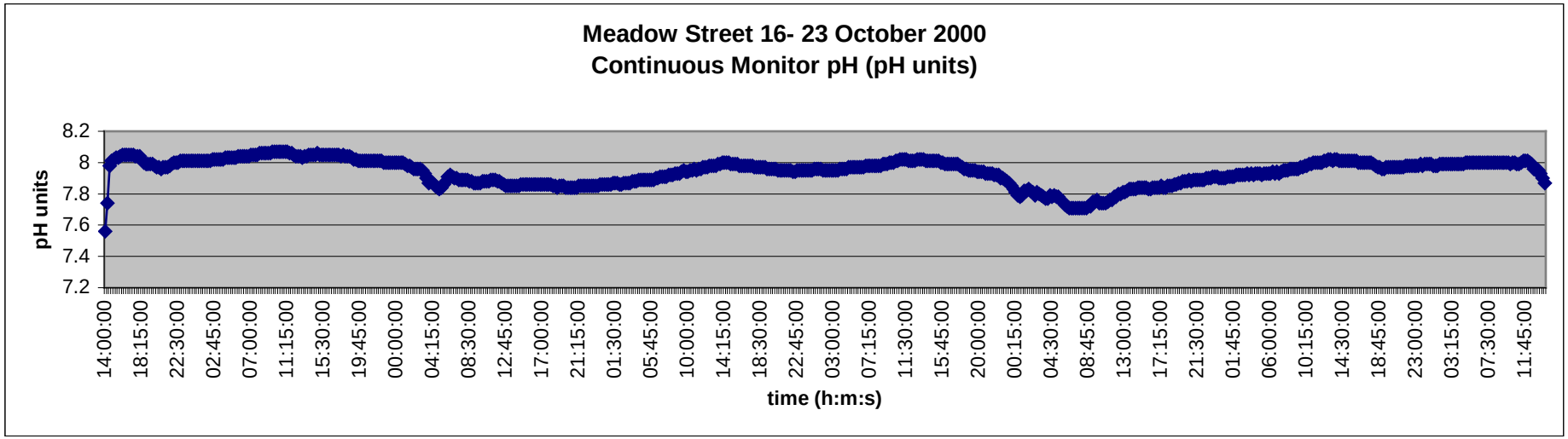


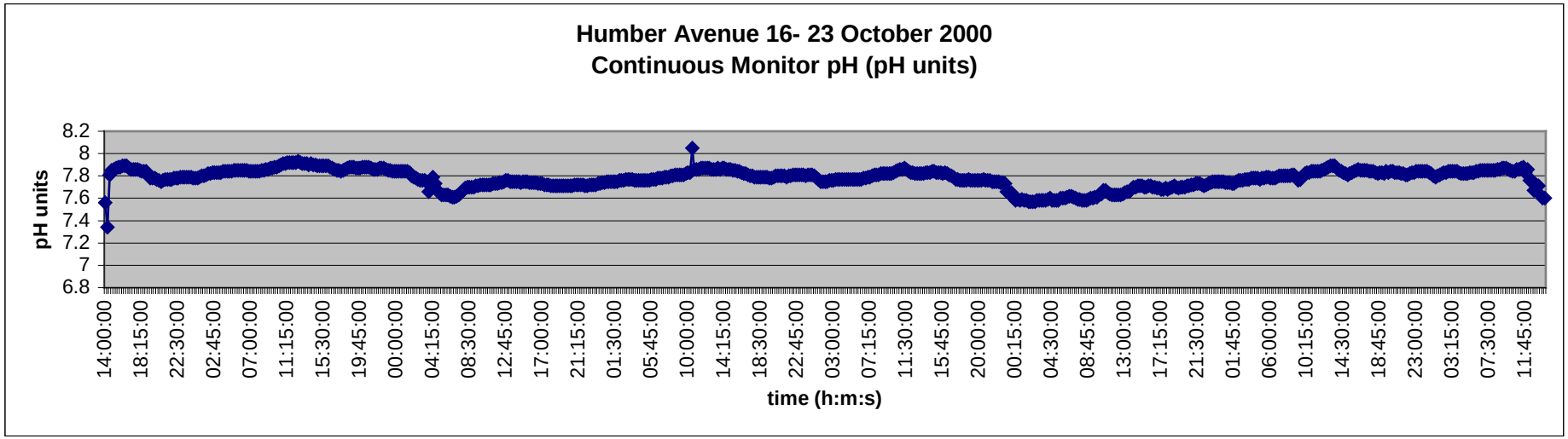

Meadow Street 16- 23 October 2000
Continuous DO (% saturation)
% saturation
120
100
80
60
40
20
0
14:00:00
18:15:00
22:30:00
02:45:00
07:00:00
11:15:00
15:30:00
19:45:00
00:00:00
04:15:00
08:30:00
12:45:00
17:00:00
21:15:00
01:30:00
05:45:00
10:00:00
14:15:00
18:30:00
22:45:00
03:00:00
07:15:00
11:30:00
15:45:00
20:00:00
00:15:00
04:30:00
08:45:00
13:00:00
17:15:00
21:30:00
01:45:00
06:00:00
10:15:00
14:30:00
18:45:00
23:00:00
03:15:00
07:30:00
11:45:00
time (h:m:s)

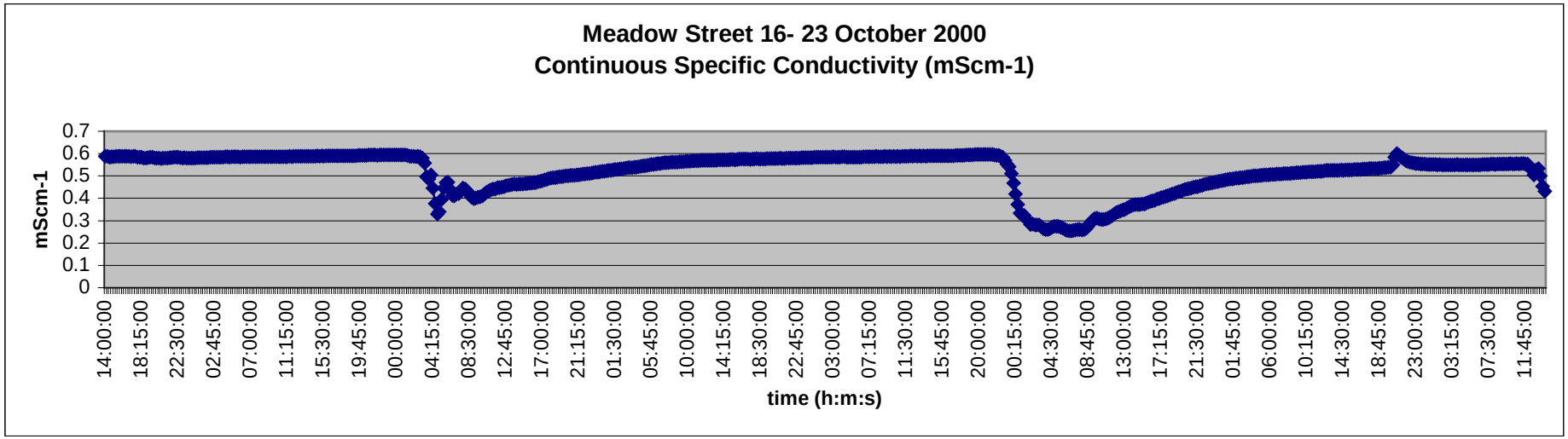

Humber Avenue 16- 23 October 2000
Continuous DO (% saturation)
% saturation
160
140
120
100
80
60
40
20
0
14:00:00
18:00:00
22:00:00
02:00:00
06:00:00
10:00:00
14:00:00
18:00:00
22:00:00
02:00:00
06:00:00
10:00:00
14:00:00
18:00:00
22:00:00
02:00:00
06:00:00
10:00:00
14:00:00
18:00:00
22:00:00
02:00:00
06:00:00
10:00:00
14:00:00
18:00:00
22:00:00
02:00:00
06:00:00
10:00:00
14:00:00
18:00:00
22:00:00
02:00:00
06:00:00
10:00:00
14:00:00
time (h:m:s)

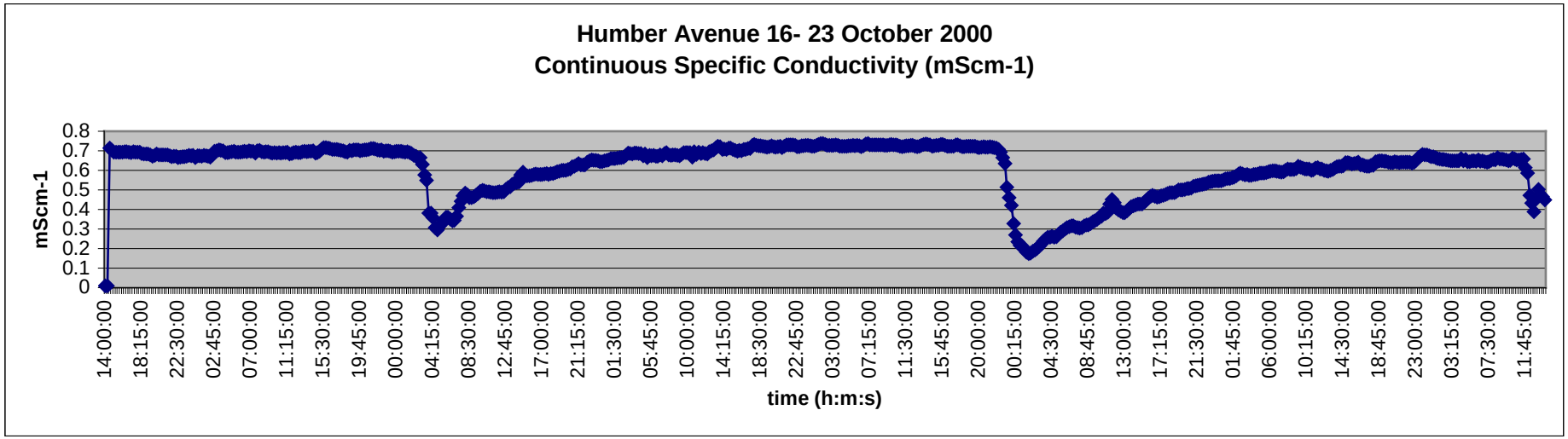

Meadow Street 16- 23 October 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
0.25
0.2
0.15
0.1
0.05
0
14:00:00
18:15:00
22:30:00
02:45:00
07:00:00
11:15:00
15:30:00
19:45:00
00:00:00
04:15:00
08:30:00
12:45:00
17:00:00
21:15:00
01:30:00
05:45:00
10:00:00
14:15:00
18:30:00
22:45:00
03:00:00
07:15:00
11:30:00
15:45:00
20:00:00
00:15:00
04:30:00
08:45:00
13:00:00
17:15:00
21:30:00
01:45:00
06:00:00
10:15:00
14:30:00
18:45:00
23:00:00
03:15:00
07:30:00
11:45:00
time (h:m:s)


Humber Avenue 16- 23 October 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
14:00:00
18:15:00
22:30:00
02:45:00
07:00:00
11:15:00
15:30:00
19:45:00
00:00:00
04:15:00
08:30:00
12:45:00
17:00:00
21:15:00
01:30:00
05:45:00
10:00:00
14:15:00
18:30:00
22:45:00
03:00:00
07:15:00
11:30:00
15:45:00
20:00:00
00:15:00
04:30:00
08:45:00
13:00:00
17:15:00
21:30:00
01:45:00
06:00:00
10:15:00
14:30:00
18:45:00
23:00:00
03:15:00
07:30:00
11:45:00
time (h:m:s)

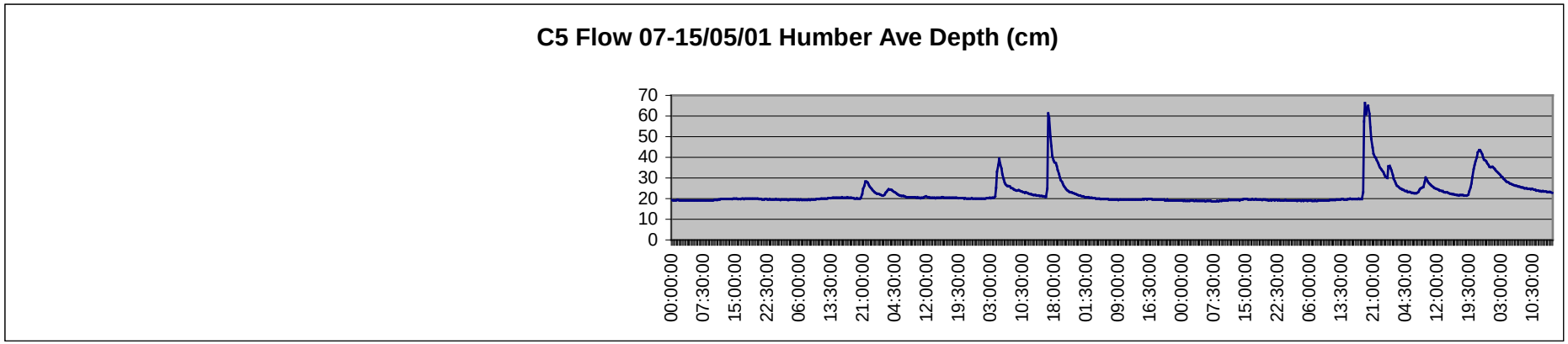

Meadow Street 16- 23 October 2000
Continuous Monitor pH (pH units)
pH units
8.2
8
7.8
7.6
7.4
7.2
14:00:00
18:15:00
22:30:00
02:45:00
07:00:00
11:15:00
15:30:00
19:45:00
00:00:00
04:15:00
08:30:00
12:45:00
17:00:00
21:15:00
01:30:00
05:45:00
10:00:00
14:15:00
18:30:00
22:45:00
03:00:00
07:15:00
11:30:00
15:45:00
20:00:00
00:15:00
04:30:00
08:45:00
13:00:00
17:15:00
21:30:00
01:45:00
06:00:00
10:15:00
14:30:00
18:45:00
23:00:00
03:15:00
07:30:00
11:45:00
time (h:m:s)

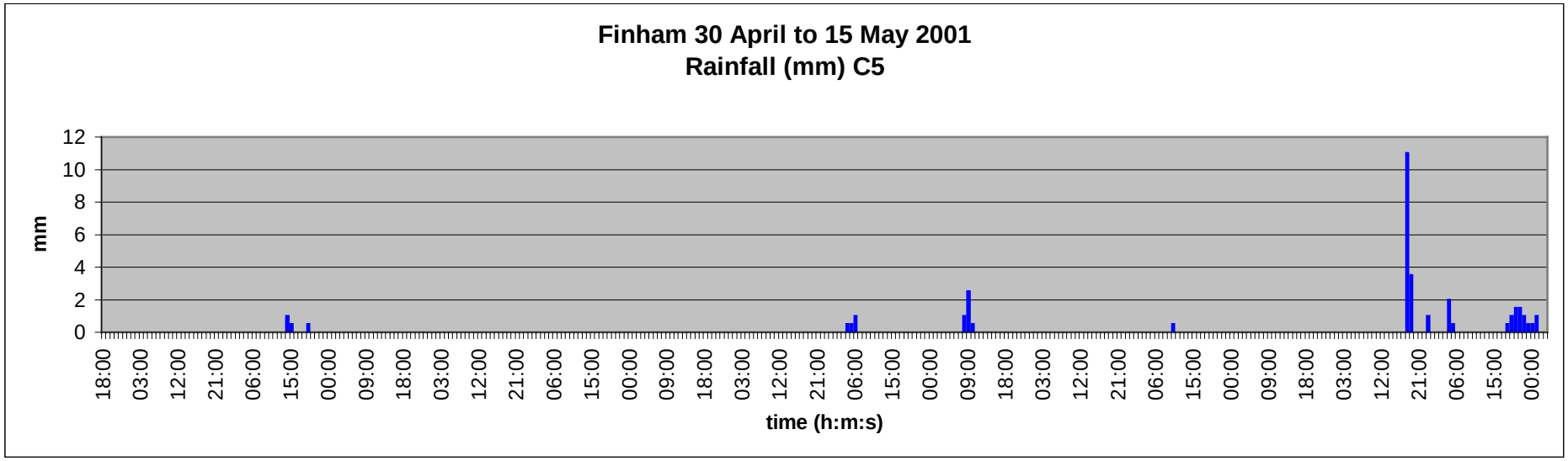

Humber Avenue 16- 23 October 2000
Continuous Monitor pH (pH units)
pH units
8.2
8
7.8
7.6
7.4
7.2
7
6.8
14:00:00
18:15:00
22:30:00
02:45:00
07:00:00
11:15:00
15:30:00
19:45:00
00:00:00
04:15:00
08:30:00
12:45:00
17:00:00
21:15:00
01:30:00
05:45:00
10:00:00
14:15:00
18:30:00
22:45:00
03:00:00
07:15:00
11:30:00
15:45:00
20:00:00
00:15:00
04:30:00
08:45:00
13:00:00
17:15:00
21:30:00
01:45:00
06:00:00
10:15:00
14:30:00
18:45:00
23:00:00
03:15:00
07:30:00
11:45:00
time (h:m:s)

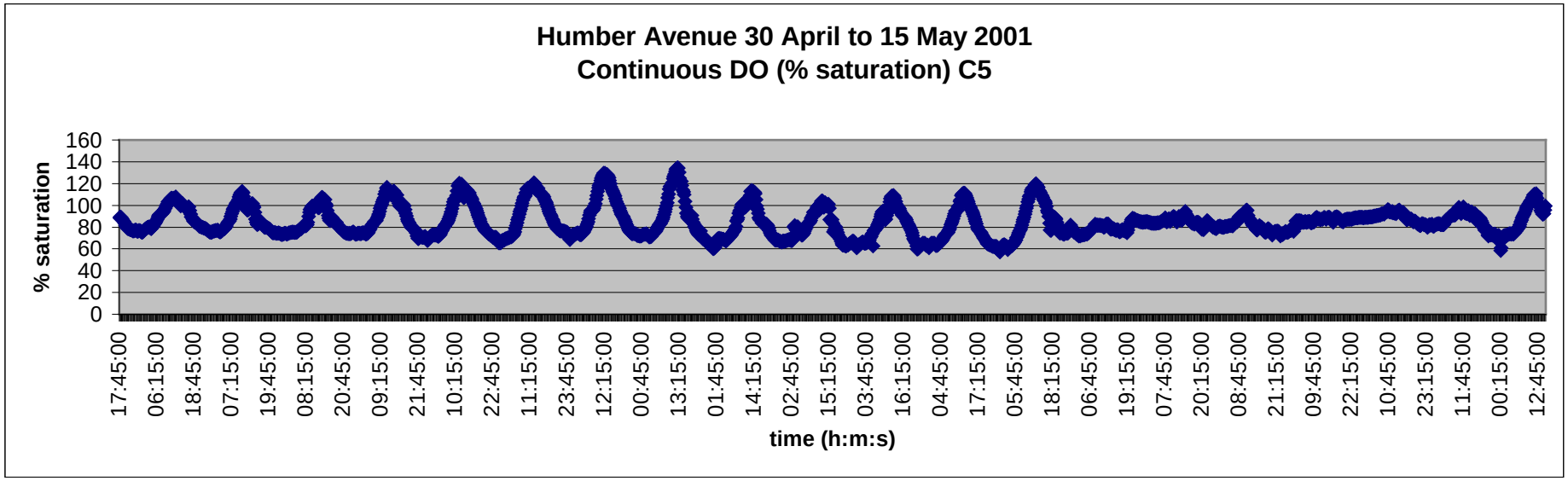

Meadow Street 16- 23 October 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
14:00:00
18:15:00
22:30:00
02:45:00
07:00:00
11:15:00
15:30:00
19:45:00
00:00:00
04:15:00
08:30:00
12:45:00
17:00:00
21:15:00
01:30:00
05:45:00
10:00:00
14:15:00
18:30:00
22:45:00
03:00:00
07:15:00
11:30:00
15:45:00
20:00:00
00:15:00
04:30:00
08:45:00
13:00:00
17:15:00
21:30:00
01:45:00
06:00:00
10:15:00
14:30:00
18:45:00
23:00:00
03:15:00
07:30:00
11:45:00
time (h:m:s)

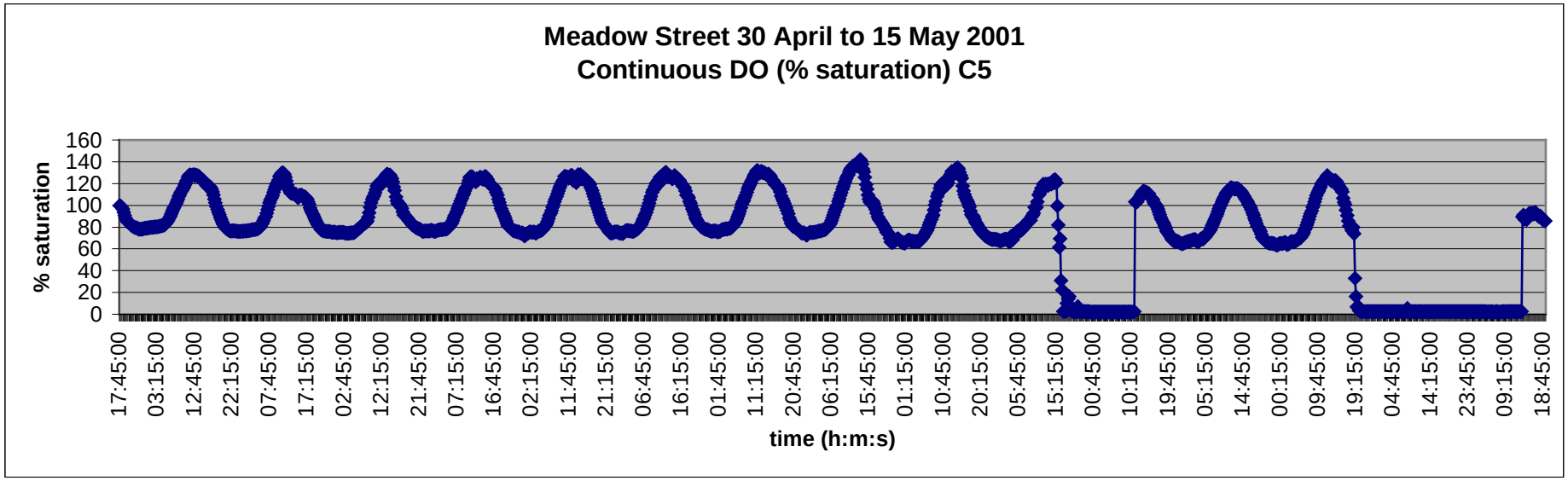

Humber Avenue 16- 23 October 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
14:00:00
18:15:00
22:30:00
02:45:00
07:00:00
11:15:00
15:30:00
19:45:00
00:00:00
04:15:00
08:30:00
12:45:00
17:00:00
21:15:00
01:30:00
05:45:00
10:00:00
14:15:00
18:30:00
22:45:00
03:00:00
07:15:00
11:30:00
15:45:00
20:00:00
00:15:00
04:30:00
08:45:00
13:00:00
17:15:00
21:30:00
01:45:00
06:00:00
10:15:00
14:30:00
18:45:00
23:00:00
03:15:00
07:30:00
11:45:00
time (h:m:s)

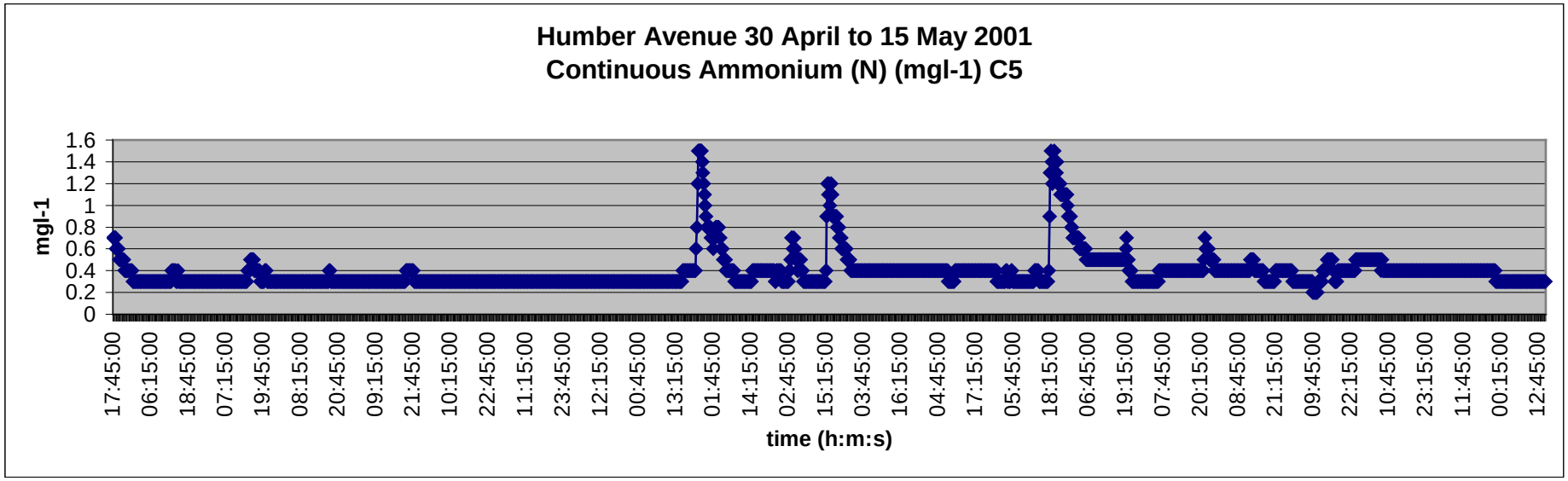
C5 Depth and Continuous monitors

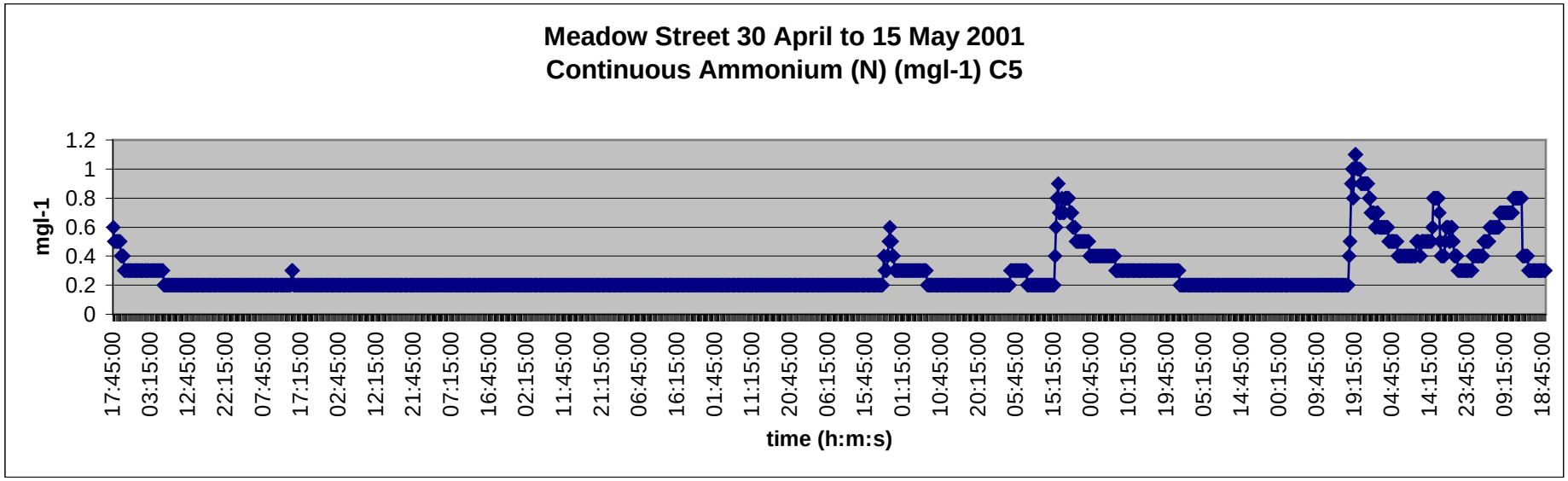


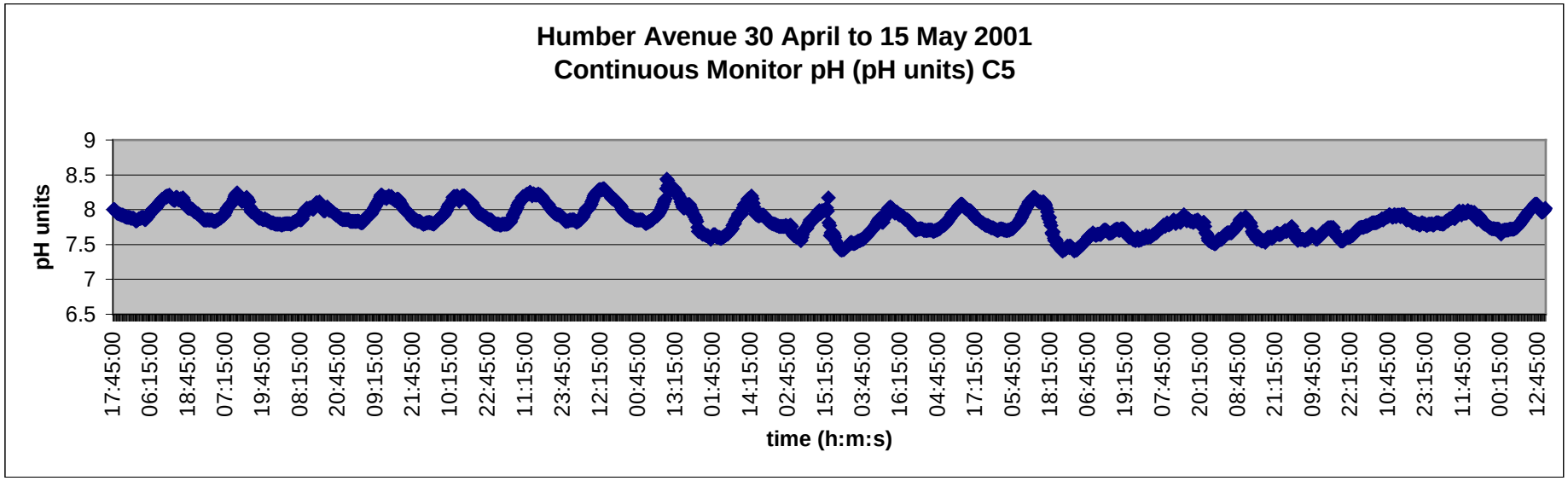


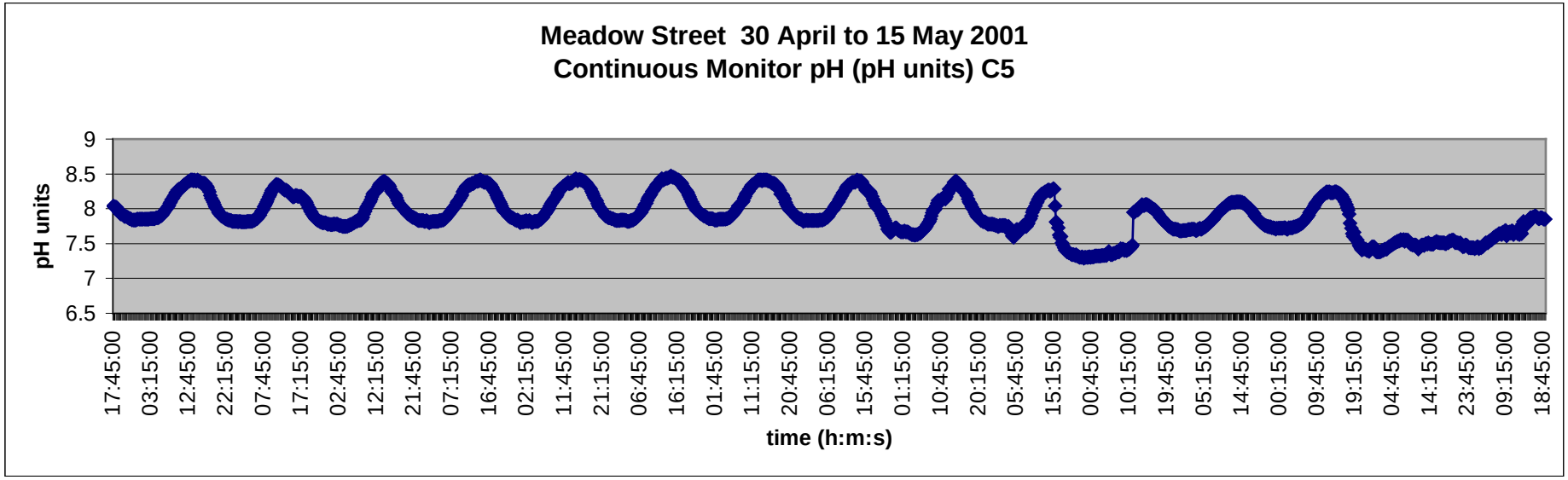

Humber Avenue 30 April to 15 May 2001
Continuous DO (% saturation) C5
% saturation
160
140
120
100
80
60
40
20
0
17:45:00
06:15:00
18:45:00
07:15:00
19:45:00
08:15:00
20:45:00
09:15:00
21:45:00
10:15:00
22:45:00
11:15:00
23:45:00
12:15:00
00:45:00
13:15:00
01:45:00
14:15:00
02:45:00
15:15:00
03:45:00
16:15:00
04:45:00
17:15:00
05:45:00
18:15:00
06:45:00
19:15:00
07:45:00
20:15:00
08:45:00
21:15:00
09:45:00
22:15:00
10:45:00
23:15:00
11:45:00
00:15:00
12:45:00
time (h:m:s)

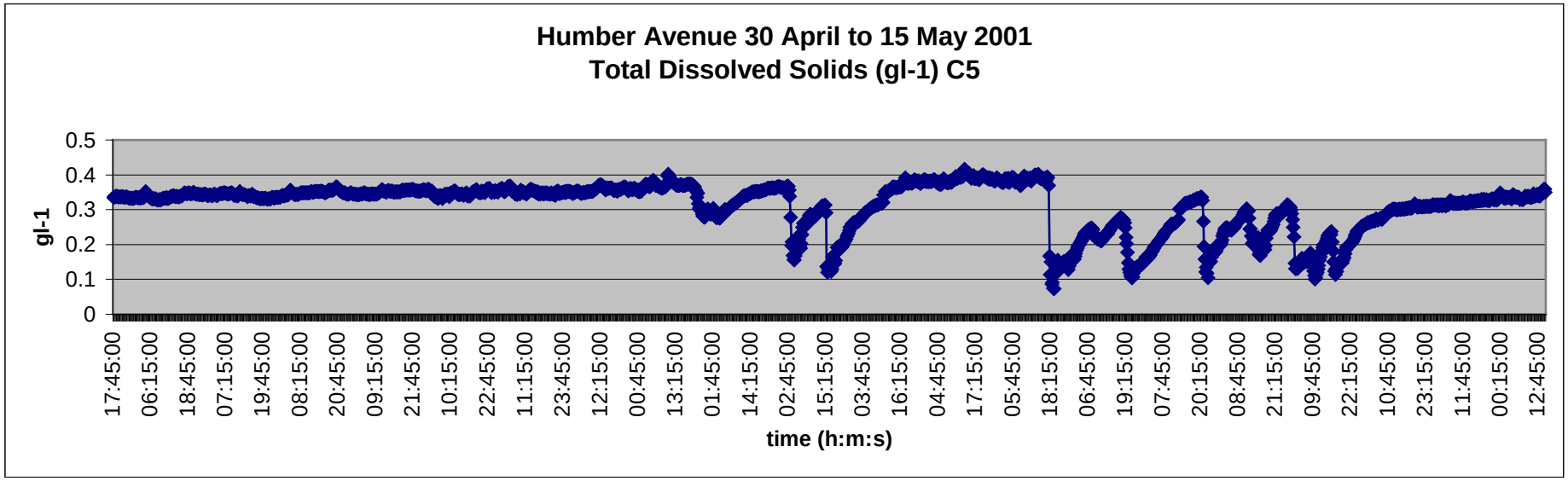

Meadow Street 30 April to 15 May 2001
Continuous DO (% saturation) C5
% saturation
160
140
120
100
80
60
40
20
0
17:45:00
03:15:00
12:45:00
22:15:00
07:45:00
17:15:00
02:45:00
12:15:00
21:45:00
07:15:00
16:45:00
02:15:00
11:45:00
21:15:00
06:45:00
16:15:00
01:45:00
11:15:00
20:45:00
06:15:00
15:45:00
01:15:00
10:45:00
20:15:00
05:45:00
15:15:00
00:45:00
10:15:00
19:45:00
05:15:00
14:45:00
00:15:00
09:45:00
19:15:00
04:45:00
14:15:00
23:45:00
09:15:00
18:45:00
time (h:m:s)

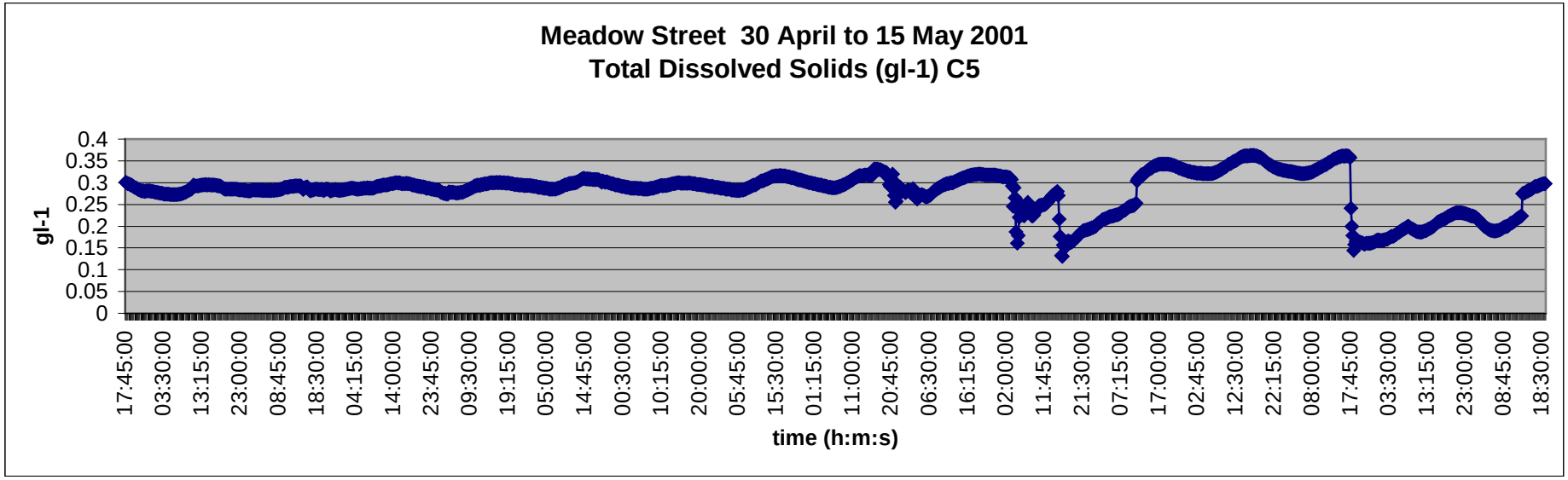

Humber Avenue 30 April to 15 May 2001
Continuous Ammonium (N) (mgl-1) C5
mgl-1
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
17:45:00
06:15:00
18:45:00
07:15:00
19:45:00
08:15:00
20:45:00
09:15:00
21:45:00
10:15:00
22:45:00
11:15:00
23:45:00
12:15:00
00:45:00
13:15:00
01:45:00
14:15:00
02:45:00
15:15:00
03:45:00
16:15:00
04:45:00
17:15:00
05:45:00
18:15:00
06:45:00
19:15:00
07:45:00
20:15:00
08:45:00
21:15:00
09:45:00
22:15:00
10:45:00
23:15:00
11:45:00
00:15:00
12:45:00
time (h:m:s)

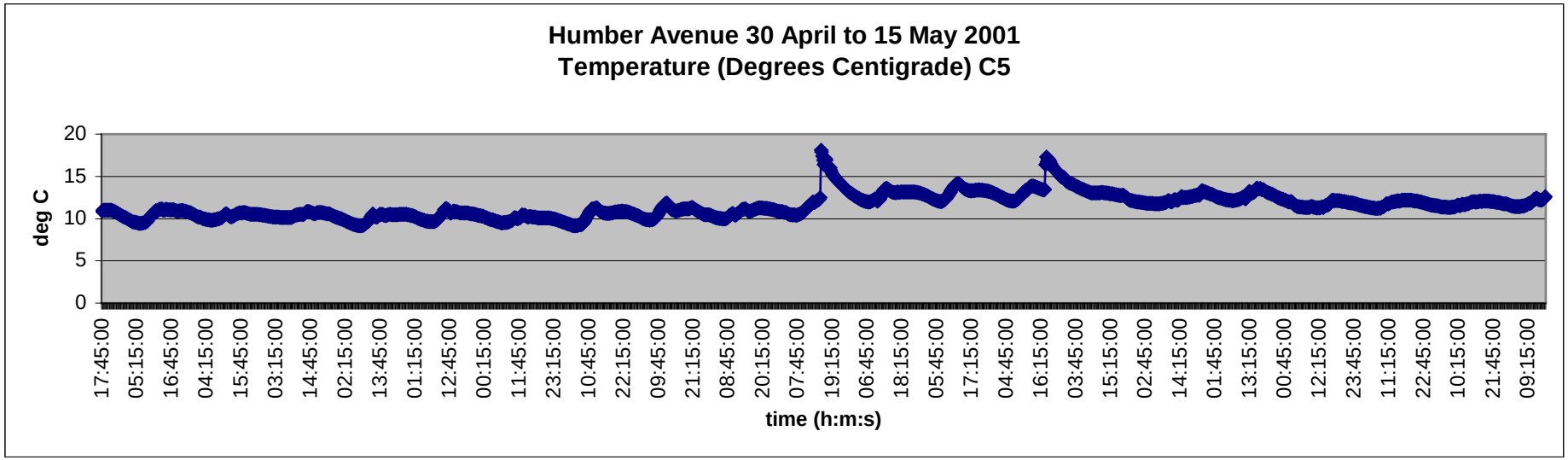

Meadow Street 30 April to 15 May 2001
Continuous Ammonium (N) (mgl-1) C5
mgl-1
1.2
1
0.8
0.6
0.4
0.2
0
17:45:00
03:15:00
12:45:00
22:15:00
07:45:00
17:15:00
02:45:00
12:15:00
21:45:00
07:15:00
16:45:00
02:15:00
11:45:00
21:15:00
06:45:00
16:15:00
01:45:00
11:15:00
20:45:00
06:15:00
15:45:00
01:15:00
10:45:00
20:15:00
05:45:00
15:15:00
00:45:00
10:15:00
19:45:00
05:15:00
14:45:00
00:15:00
09:45:00
19:15:00
04:45:00
14:15:00
23:45:00
09:15:00
18:45:00
time (h:m:s)

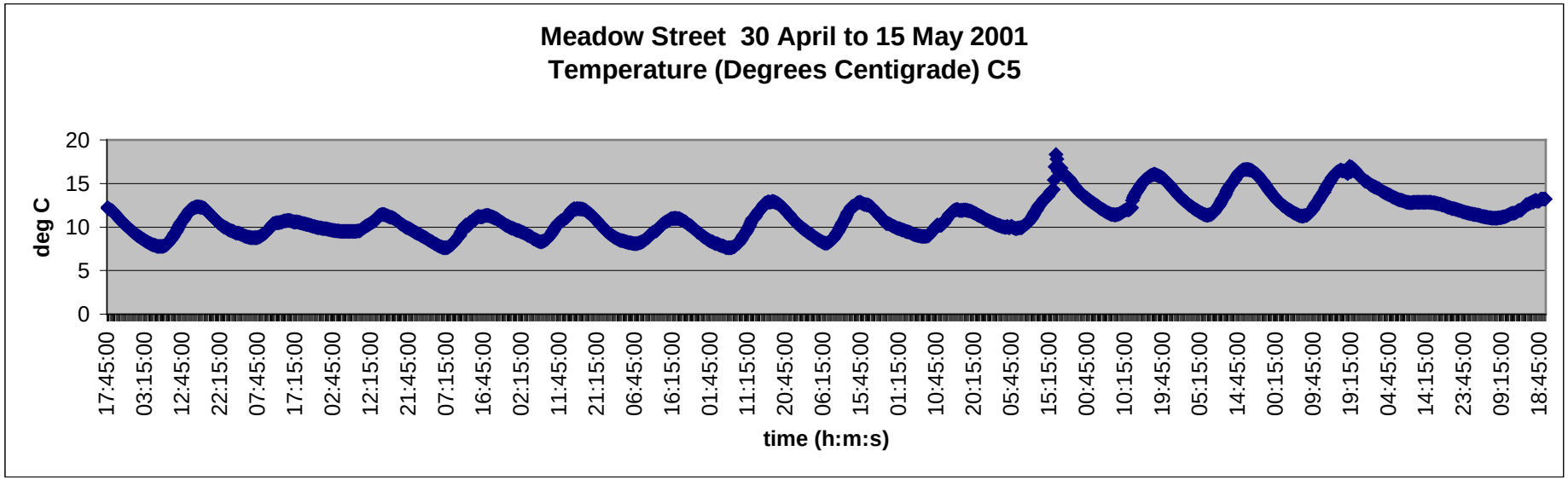

Humber Avenue 30 April to 15 May 2001
Continuous Monitor pH (pH units) C5
pH units
9
8.5
8
7.5
7
6.5
17:45:00
06:15:00
18:45:00
07:15:00
19:45:00
08:15:00
20:45:00
09:15:00
21:45:00
10:15:00
22:45:00
11:15:00
23:45:00
12:15:00
00:45:00
13:15:00
01:45:00
14:15:00
02:45:00
15:15:00
03:45:00
16:15:00
04:45:00
17:15:00
05:45:00
18:15:00
06:45:00
19:15:00
07:45:00
20:15:00
08:45:00
21:15:00
09:45:00
22:15:00
10:45:00
23:15:00
11:45:00
00:15:00
12:45:00
time (h:m:s)


Meadow Street 30 April to 15 May 2001
Continuous Monitor pH (pH units) C5
pH units
9
8.5
8
7.5
7
6.5
17:45:00
03:15:00
12:45:00
22:15:00
07:45:00
17:15:00
02:45:00
12:15:00
21:45:00
07:15:00
16:45:00
02:15:00
11:45:00
21:15:00
06:45:00
16:15:00
01:45:00
11:15:00
20:45:00
06:15:00
15:45:00
01:15:00
10:45:00
20:15:00
05:45:00
15:15:00
00:45:00
10:15:00
19:45:00
05:15:00
14:45:00
00:15:00
09:45:00
19:15:00
04:45:00
14:15:00
23:45:00
09:15:00
18:45:00
time (h:m:s)

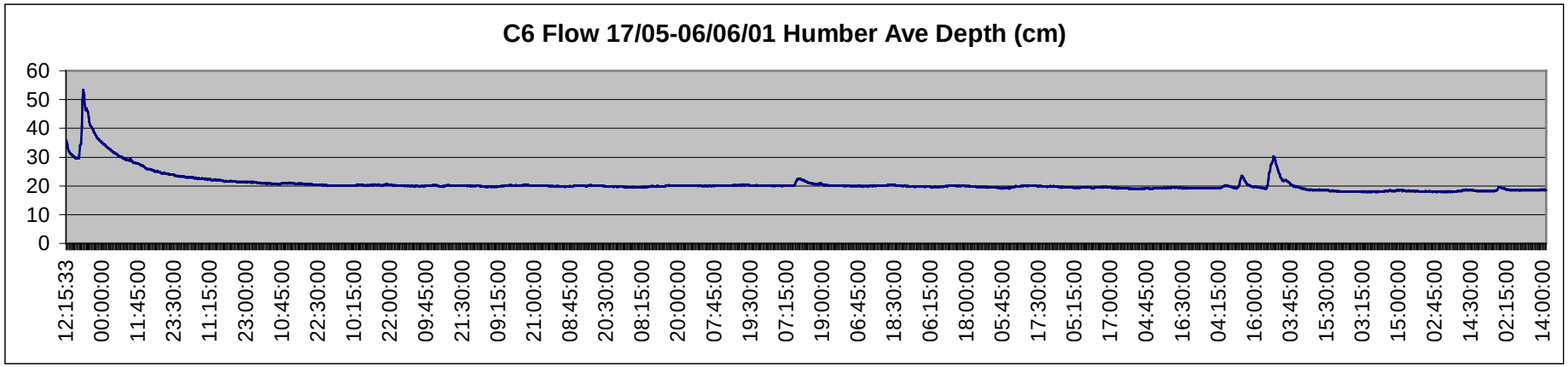

Humber Avenue 30 April to 15 May 2001
Total Dissolved Solids (gl-1) C5
gl-1
0.5
0.4
0.3
0.2
0.1
0
17:45:00
06:15:00
18:45:00
07:15:00
19:45:00
08:15:00
20:45:00
09:15:00
21:45:00
10:15:00
22:45:00
11:15:00
23:45:00
12:15:00
00:45:00
13:15:00
01:45:00
14:15:00
02:45:00
15:15:00
03:45:00
16:15:00
04:45:00
17:15:00
05:45:00
18:15:00
06:45:00
19:15:00
07:45:00
20:15:00
08:45:00
21:15:00
09:45:00
22:15:00
10:45:00
23:15:00
11:45:00
00:15:00
12:45:00
time (h:m:s)

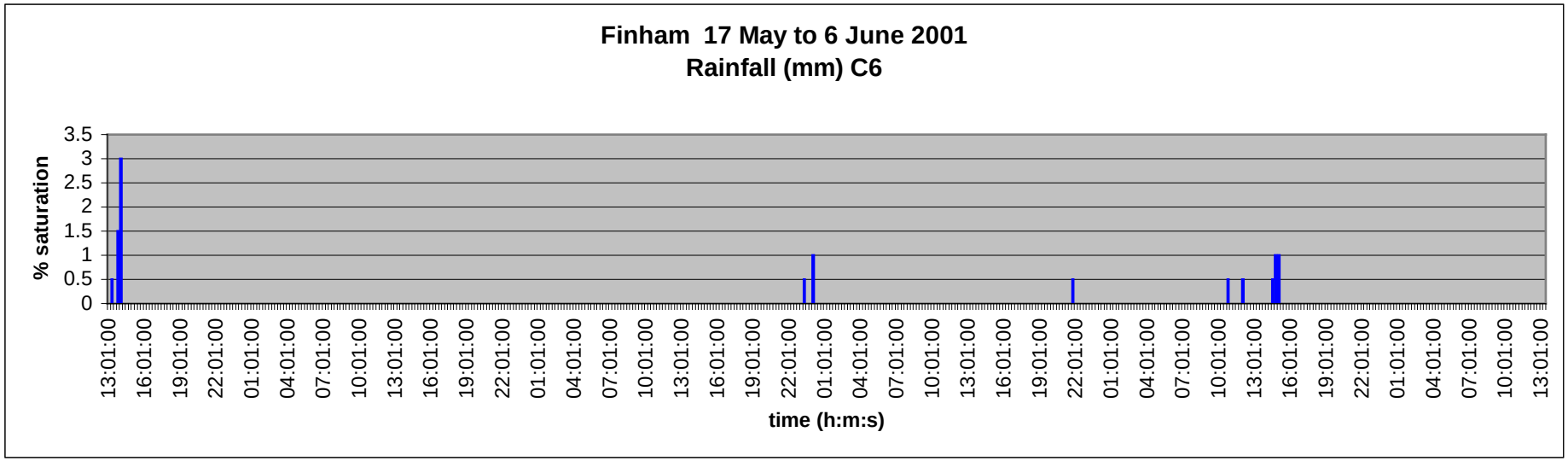

Meadow Street 30 April to 15 May 2001
Total Dissolved Solids (gl-1) C5
gl-1
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
17:45:00
03:30:00
13:15:00
23:00:00
08:45:00
18:30:00
04:15:00
14:00:00
23:45:00
09:30:00
19:15:00
05:00:00
14:45:00
00:30:00
10:15:00
20:00:00
05:45:00
15:30:00
01:15:00
11:00:00
20:45:00
06:30:00
16:15:00
02:00:00
11:45:00
21:30:00
07:15:00
17:00:00
02:45:00
12:30:00
22:15:00
08:00:00
17:45:00
03:30:00
13:15:00
23:00:00
08:45:00
18:30:00
time (h:m:s)

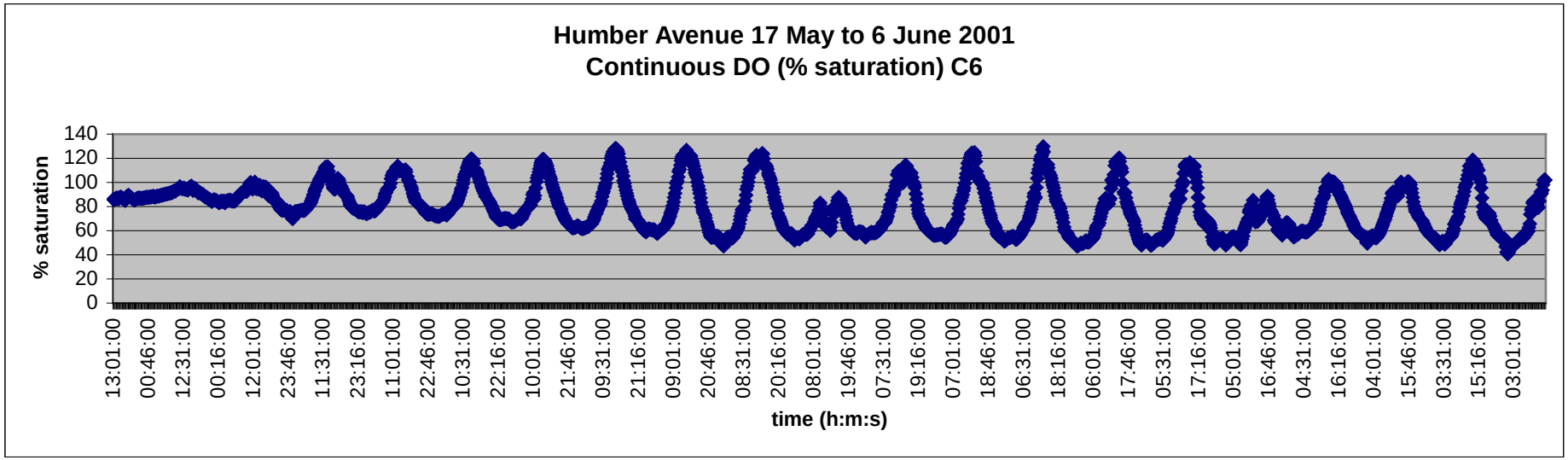

Humber Avenue 30 April to 15 May 2001
Temperature (Degrees Centigrade) C5
deg C
20
15
10
5
0
17:45:00
05:15:00
16:45:00
04:15:00
15:45:00
03:15:00
14:45:00
02:15:00
13:45:00
01:15:00
12:45:00
00:15:00
11:45:00
23:15:00
10:45:00
22:15:00
09:45:00
21:15:00
08:45:00
20:15:00
07:45:00
19:15:00
06:45:00
18:15:00
05:45:00
17:15:00
04:45:00
16:15:00
03:45:00
15:15:00
02:45:00
14:15:00
01:45:00
13:15:00
00:45:00
12:15:00
23:45:00
11:15:00
22:45:00
10:15:00
21:45:00
09:15:00
time (h:m:s)

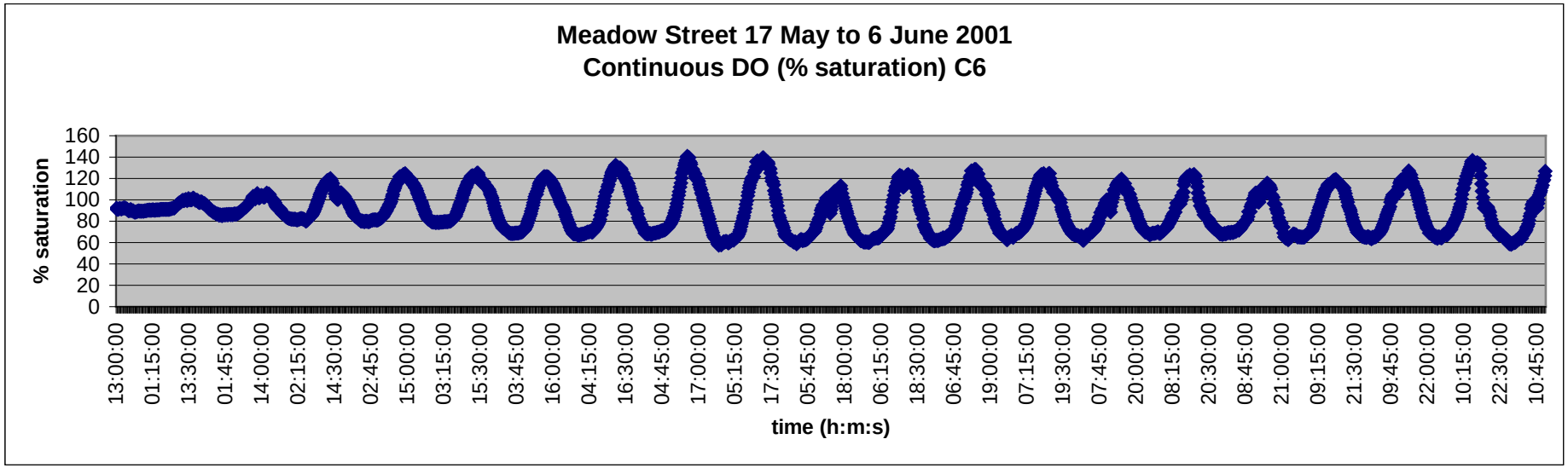

Meadow Street 30 April to 15 May 2001
Temperature (Degrees Centigrade) C5
deg C
20
15
10
5
0
17:45:00
03:15:00
12:45:00
22:15:00
07:45:00
17:15:00
02:45:00
12:15:00
21:45:00
07:15:00
16:45:00
02:15:00
11:45:00
21:15:00
06:45:00
16:15:00
01:45:00
11:15:00
20:45:00
06:15:00
15:45:00
01:15:00
10:45:00
20:15:00
05:45:00
15:15:00
00:45:00
10:15:00
19:45:00
05:15:00
14:45:00
00:15:00
09:45:00
19:15:00
04:45:00
14:15:00
23:45:00
09:15:00
18:45:00
time (h:m:s)

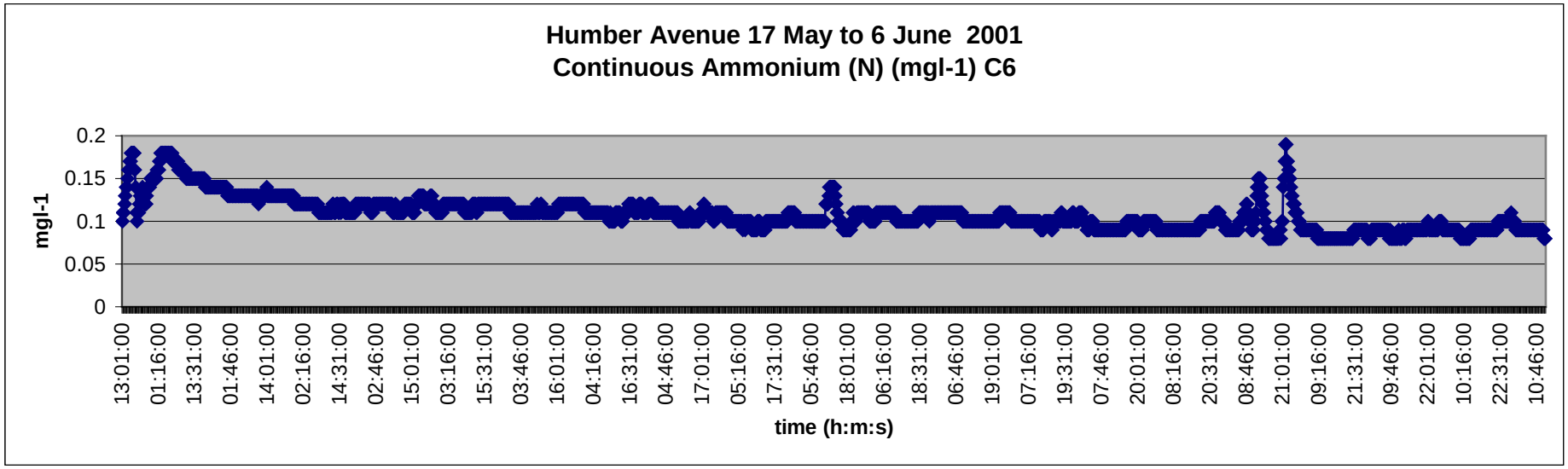
C6 Depth and Continuous monitors

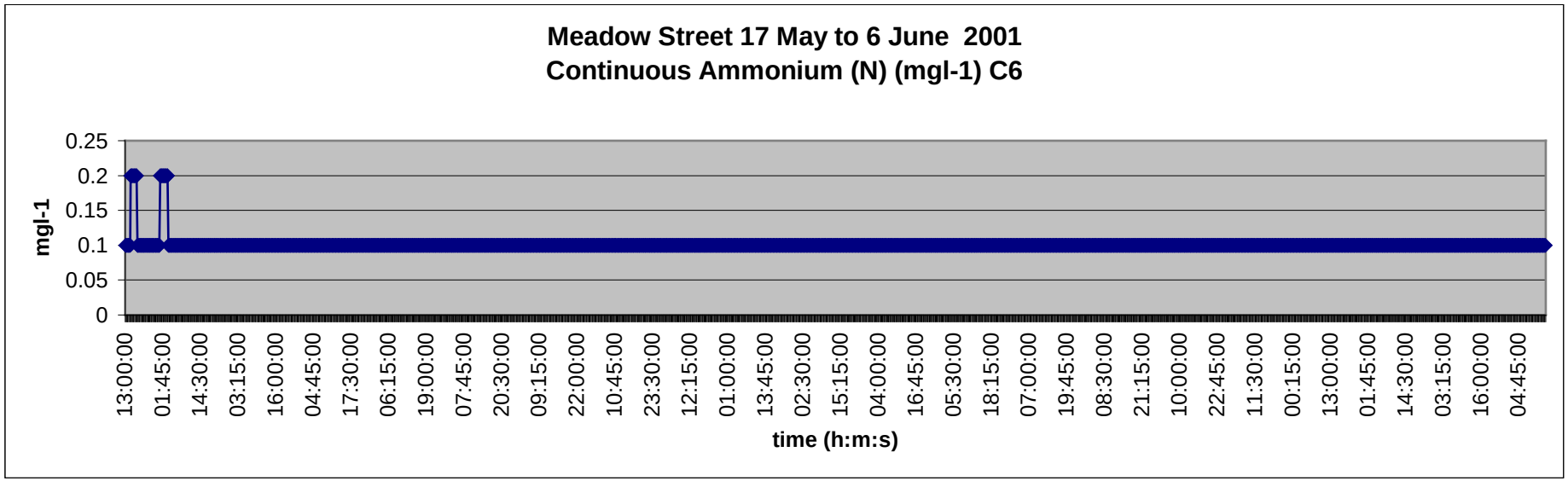


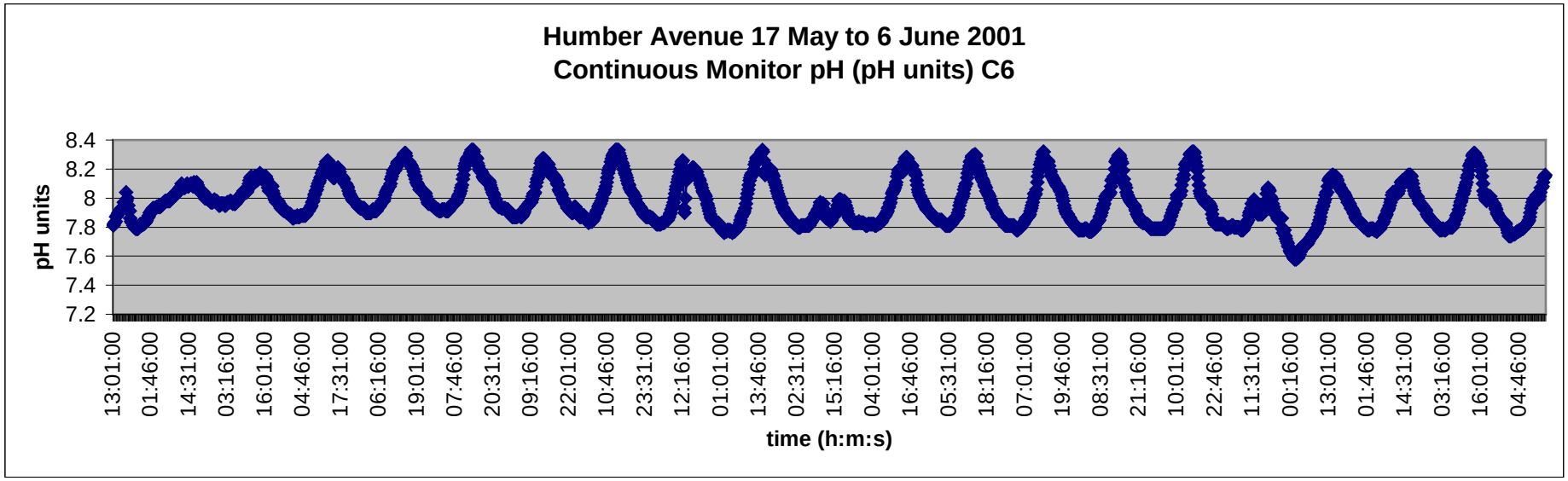


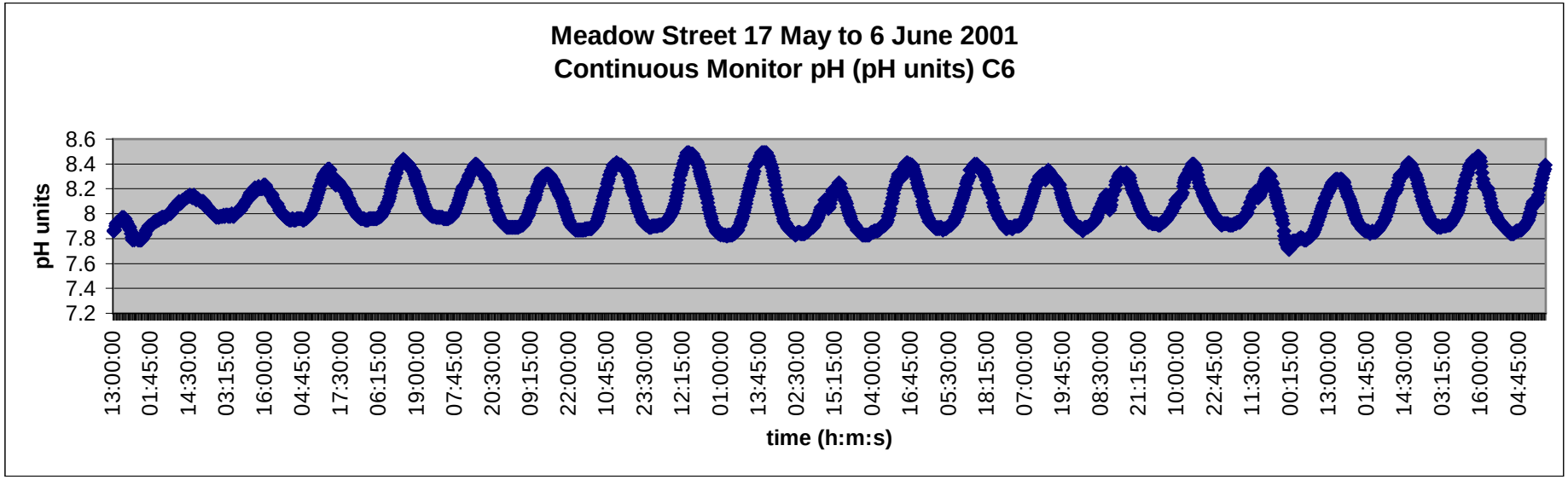

Humber Avenue 17 May to 6 June 2001
Continuous DO (% saturation) C6
% saturation
140
120
100
80
60
40
20
0
13:01:00
00:46:00
12:31:00
00:16:00
12:01:00
23:46:00
11:31:00
23:16:00
11:01:00
22:46:00
10:31:00
22:16:00
10:01:00
21:46:00
09:31:00
21:16:00
09:01:00
20:46:00
08:31:00
20:16:00
08:01:00
19:46:00
07:31:00
19:16:00
07:01:00
18:46:00
06:31:00
18:16:00
06:01:00
17:46:00
05:31:00
17:16:00
05:01:00
16:46:00
04:31:00
16:16:00
04:01:00
15:46:00
03:31:00
15:16:00
03:01:00
time (h:m:s)

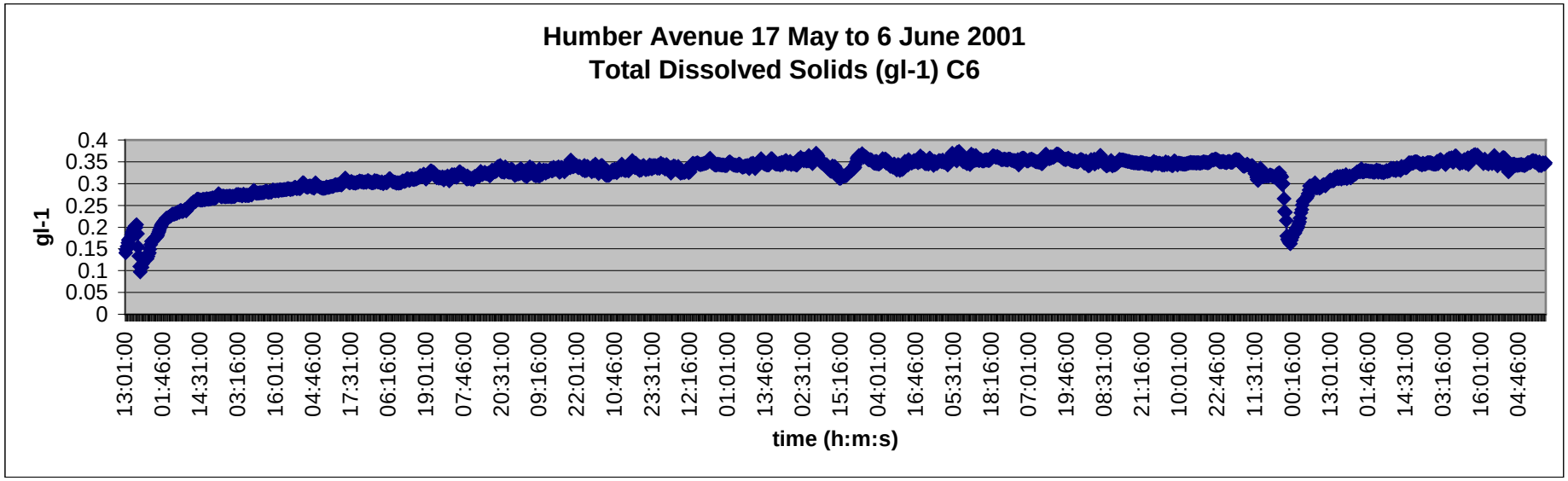

Meadow Street 17 May to 6 June 2001
Continuous DO (% saturation) C6
% saturation
160
140
120
100
80
60
40
20
0
13:00:00
01:15:00
13:30:00
01:45:00
14:00:00
02:15:00
14:30:00
02:45:00
15:00:00
03:15:00
15:30:00
03:45:00
16:00:00
04:15:00
16:30:00
04:45:00
17:00:00
05:15:00
17:30:00
05:45:00
18:00:00
06:15:00
18:30:00
06:45:00
19:00:00
07:15:00
19:30:00
07:45:00
20:00:00
08:15:00
20:30:00
08:45:00
21:00:00
09:15:00
21:30:00
09:45:00
22:00:00
10:15:00
22:30:00
10:45:00
time (h:m:s)

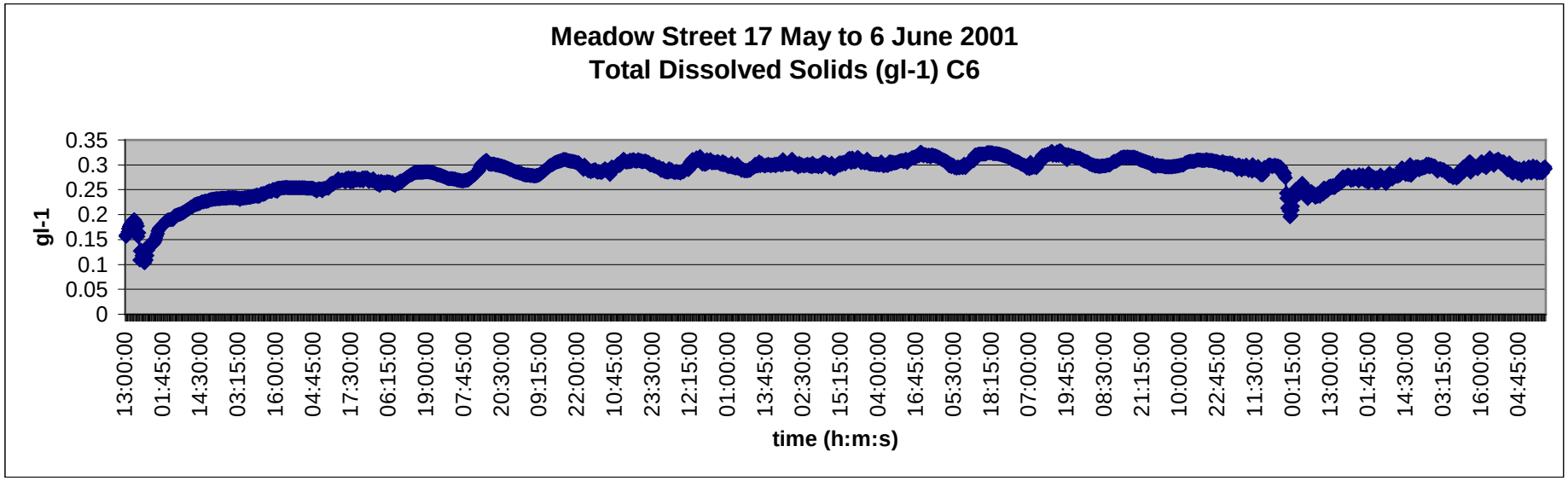

Humber Avenue 17 May to 6 June 2001
Continuous Ammonium (N) (mgl-1) C6
mgl-1
0.2
0.15
0.1
0.05
0
13:01:00
01:16:00
13:31:00
01:46:00
14:01:00
02:16:00
14:31:00
02:46:00
15:01:00
03:16:00
15:31:00
03:46:00
16:01:00
04:16:00
16:31:00
04:46:00
17:01:00
05:16:00
17:31:00
05:46:00
18:01:00
06:16:00
18:31:00
06:46:00
19:01:00
07:16:00
19:31:00
07:46:00
20:01:00
08:16:00
20:31:00
08:46:00
21:01:00
09:16:00
21:31:00
09:46:00
22:01:00
10:16:00
22:31:00
10:46:00
time (h:m:s)

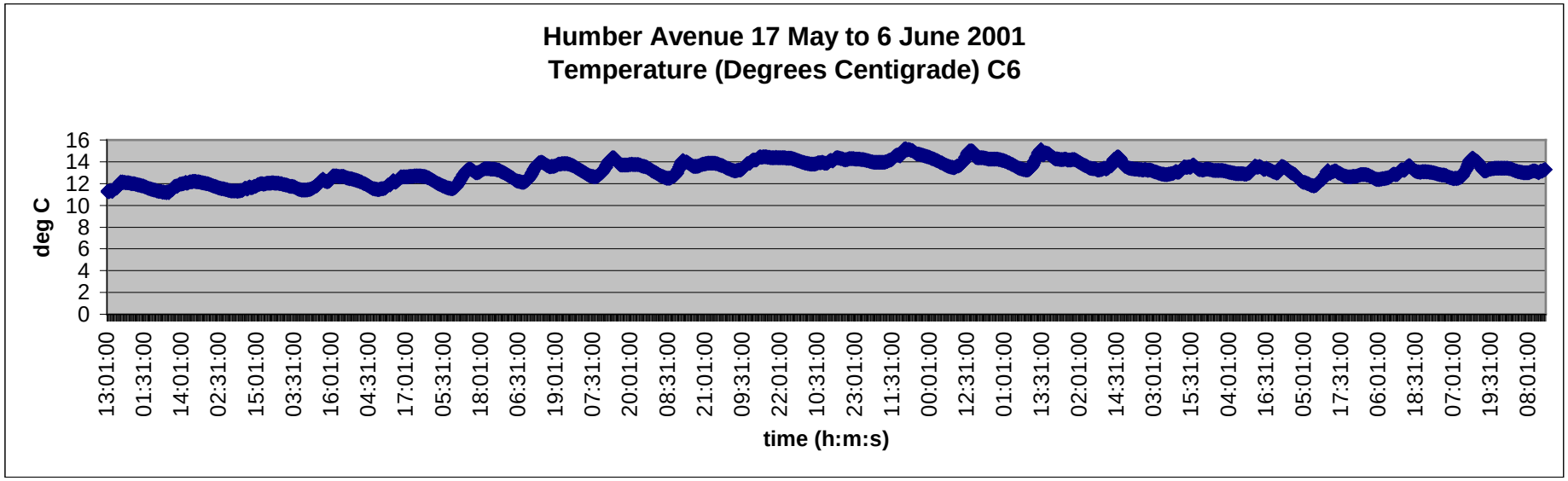

Meadow Street 17 May to 6 June 2001
Continuous Ammonium (N) (mgl-1) C6
mgl-1
0.25
0.2
0.15
0.1
0.05
0
13:00:00
01:45:00
14:30:00
03:15:00
16:00:00
04:45:00
17:30:00
06:15:00
19:00:00
07:45:00
20:30:00
09:15:00
22:00:00
10:45:00
23:30:00
12:15:00
01:00:00
13:45:00
02:30:00
15:15:00
04:00:00
16:45:00
05:30:00
18:15:00
07:00:00
19:45:00
08:30:00
21:15:00
10:00:00
22:45:00
11:30:00
00:15:00
13:00:00
01:45:00
14:30:00
03:15:00
16:00:00
04:45:00
time (h:m:s)

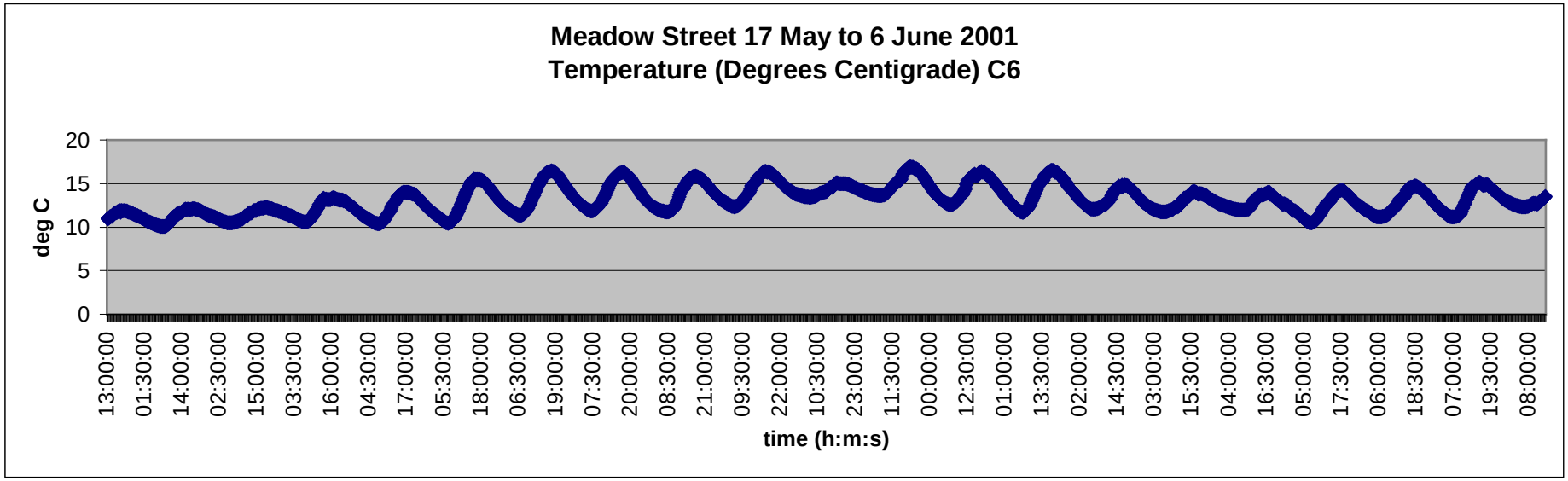

Humber Avenue 17 May to 6 June 2001
Continuous Monitor pH (pH units) C6
pH units
8.4
8.2
8
7.8
7.6
7.4
7.2
13:01:00
01:46:00
14:31:00
03:16:00
16:01:00
04:46:00
17:31:00
06:16:00
19:01:00
07:46:00
20:31:00
09:16:00
22:01:00
10:46:00
23:31:00
12:16:00
01:01:00
13:46:00
02:31:00
15:16:00
04:01:00
16:46:00
05:31:00
18:16:00
07:01:00
19:46:00
08:31:00
21:16:00
10:01:00
22:46:00
11:31:00
00:16:00
13:01:00
01:46:00
14:31:00
03:16:00
16:01:00
04:46:00
time (h:m:s)


Meadow Street 17 May to 6 June 2001
Continuous Monitor pH (pH units) C6
pH units
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
13:00:00
01:45:00
14:30:00
03:15:00
16:00:00
04:45:00
17:30:00
06:15:00
19:00:00
07:45:00
20:30:00
09:15:00
22:00:00
10:45:00
23:30:00
12:15:00
01:00:00
13:45:00
02:30:00
15:15:00
04:00:00
16:45:00
05:30:00
18:15:00
07:00:00
19:45:00
08:30:00
21:15:00
10:00:00
22:45:00
11:30:00
00:15:00
13:00:00
01:45:00
14:30:00
03:15:00
16:00:00
04:45:00
time (h:m:s)

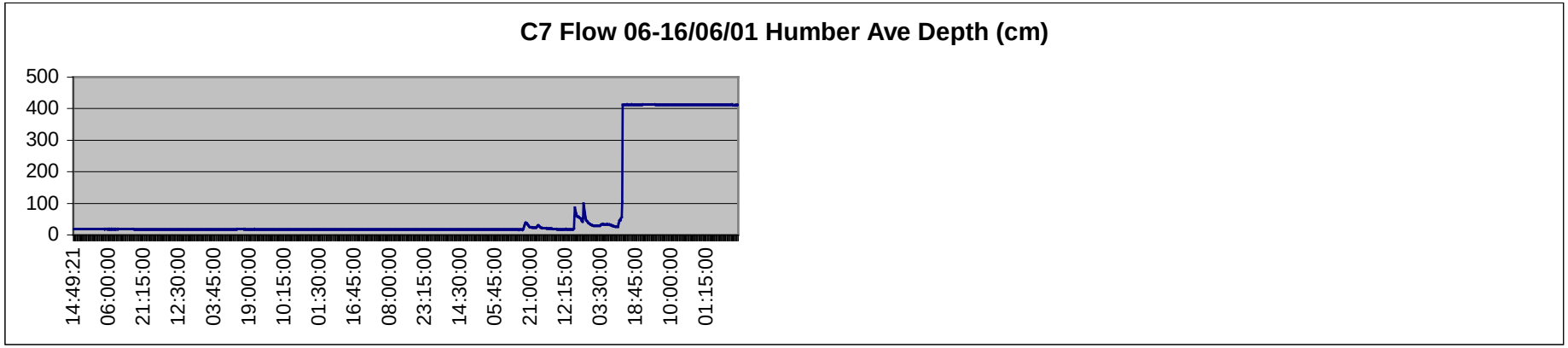

Humber Avenue 17 May to 6 June 2001
Total Dissolved Solids (gl-1) C6
gl-1
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
13:01:00
01:46:00
14:31:00
03:16:00
16:01:00
04:46:00
17:31:00
06:16:00
19:01:00
07:46:00
20:31:00
09:16:00
22:01:00
10:46:00
23:31:00
12:16:00
01:01:00
13:46:00
02:31:00
15:16:00
04:01:00
16:46:00
05:31:00
18:16:00
07:01:00
19:46:00
08:31:00
21:16:00
10:01:00
22:46:00
11:31:00
00:16:00
13:01:00
01:46:00
14:31:00
03:16:00
16:01:00
04:46:00
time (h:m:s)

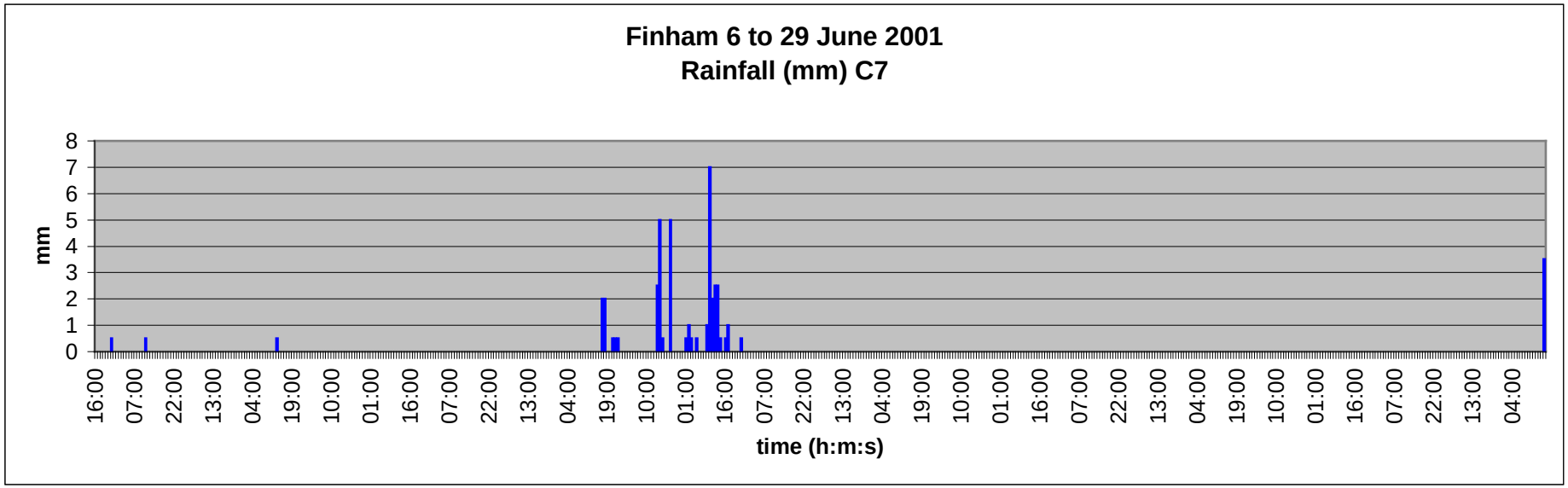

Meadow Street 17 May to 6 June 2001
Total Dissolved Solids (gl-1) C6
gl-1
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
13:00:00
01:45:00
14:30:00
03:15:00
16:00:00
04:45:00
17:30:00
06:15:00
19:00:00
07:45:00
20:30:00
09:15:00
22:00:00
10:45:00
23:30:00
12:15:00
01:00:00
13:45:00
02:30:00
15:15:00
04:00:00
16:45:00
05:30:00
18:15:00
07:00:00
19:45:00
08:30:00
21:15:00
10:00:00
22:45:00
11:30:00
00:15:00
13:00:00
01:45:00
14:30:00
03:15:00
16:00:00
04:45:00
time (h:m:s)

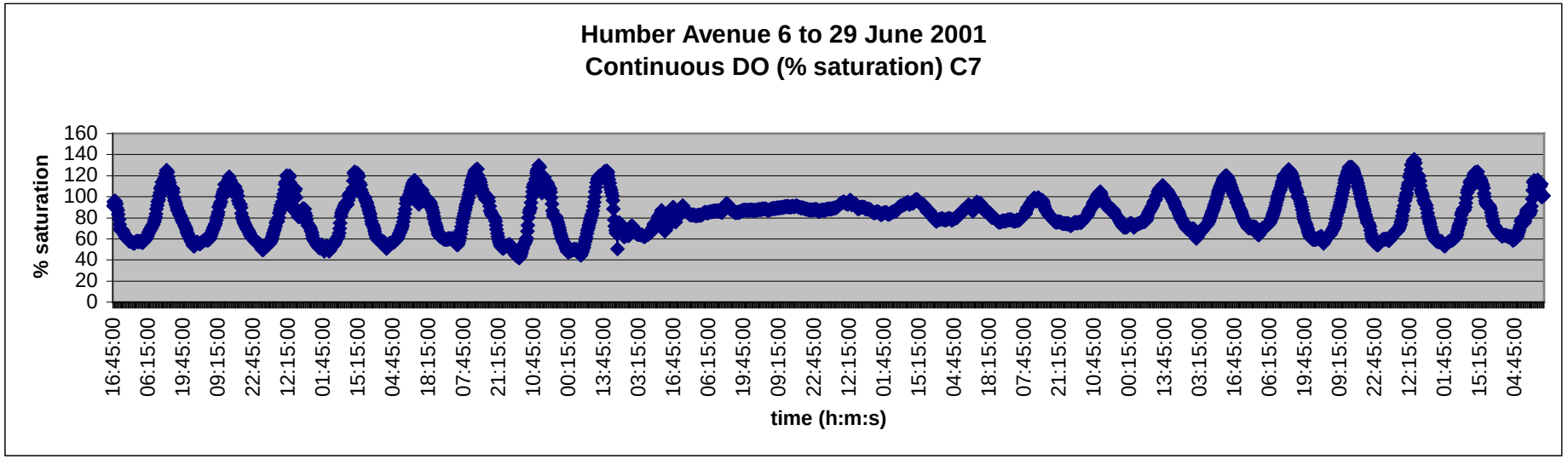

Humber Avenue 17 May to 6 June 2001
Temperature (Degrees Centigrade) C6
deg C
16
14
12
10
8
6
4
2
0
13:01:00
01:31:00
14:01:00
02:31:00
15:01:00
03:31:00
16:01:00
04:31:00
17:01:00
05:31:00
18:01:00
06:31:00
19:01:00
07:31:00
20:01:00
08:31:00
21:01:00
09:31:00
22:01:00
10:31:00
23:01:00
11:31:00
00:01:00
12:31:00
01:01:00
13:31:00
02:01:00
14:31:00
03:01:00
15:31:00
04:01:00
16:31:00
05:01:00
17:31:00
06:01:00
18:31:00
07:01:00
19:31:00
08:01:00
time (h:m:s)

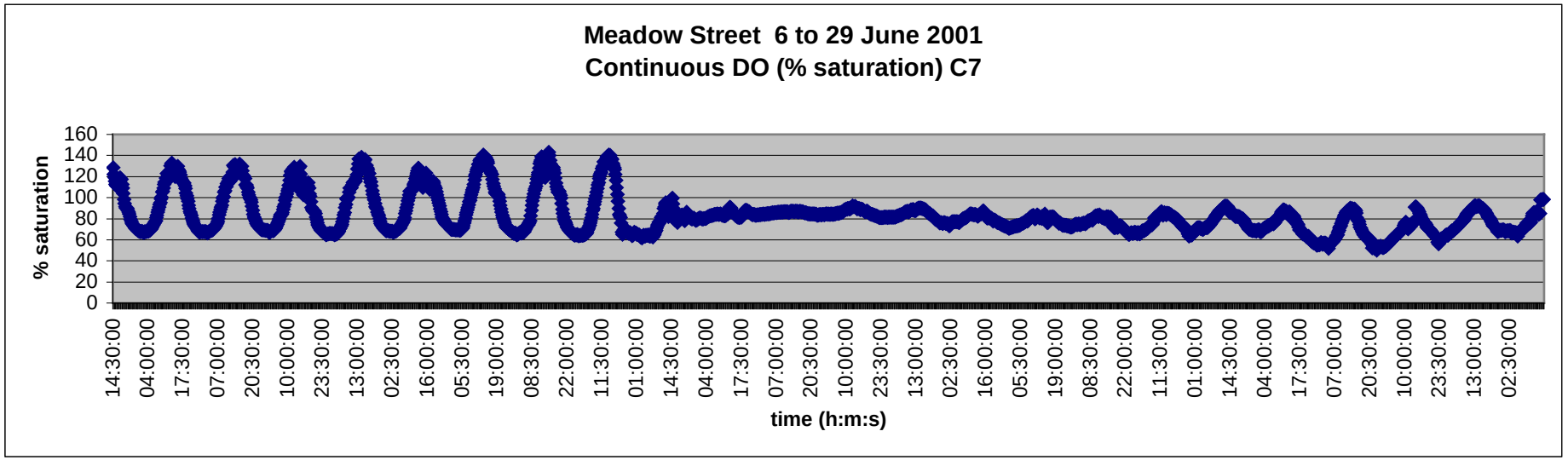

Meadow Street 17 May to 6 June 2001
Temperature (Degrees Centigrade) C6
deg C
20
15
10
5
0
13:00:00
01:30:00
14:00:00
02:30:00
15:00:00
03:30:00
16:00:00
04:30:00
17:00:00
05:30:00
18:00:00
06:30:00
19:00:00
07:30:00
20:00:00
08:30:00
21:00:00
09:30:00
22:00:00
10:30:00
23:00:00
11:30:00
00:00:00
12:30:00
01:00:00
13:30:00
02:00:00
14:30:00
03:00:00
15:30:00
04:00:00
16:30:00
05:00:00
17:30:00
06:00:00
18:30:00
07:00:00
19:30:00
08:00:00
time (h:m:s)

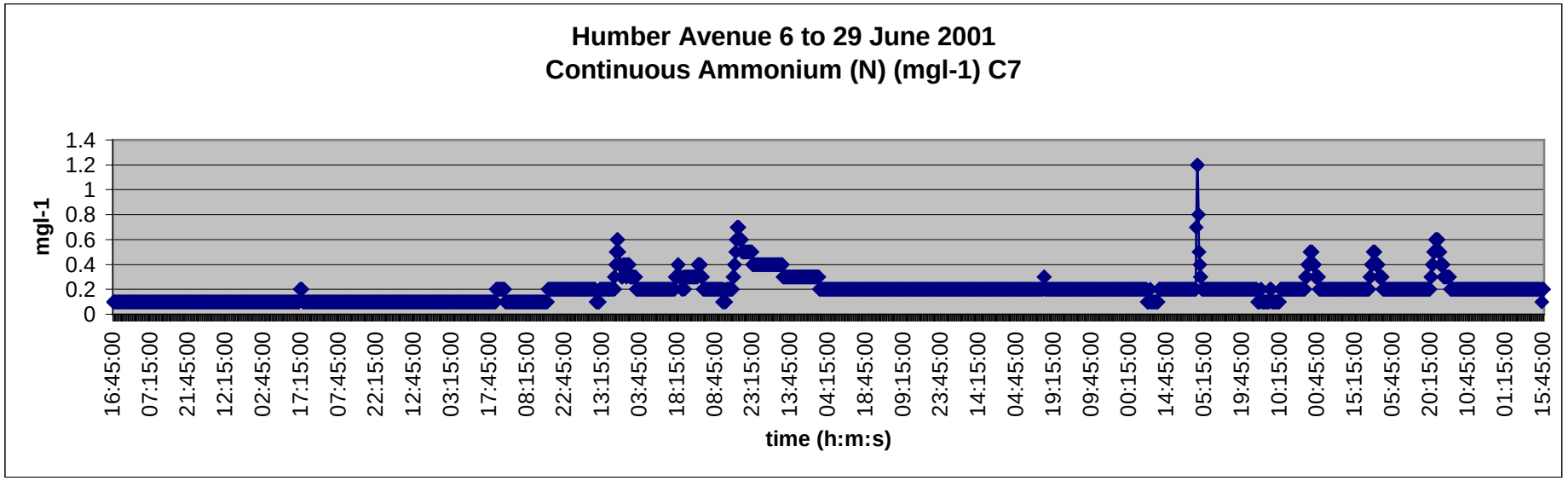
C7 Depth and Continuous monitors

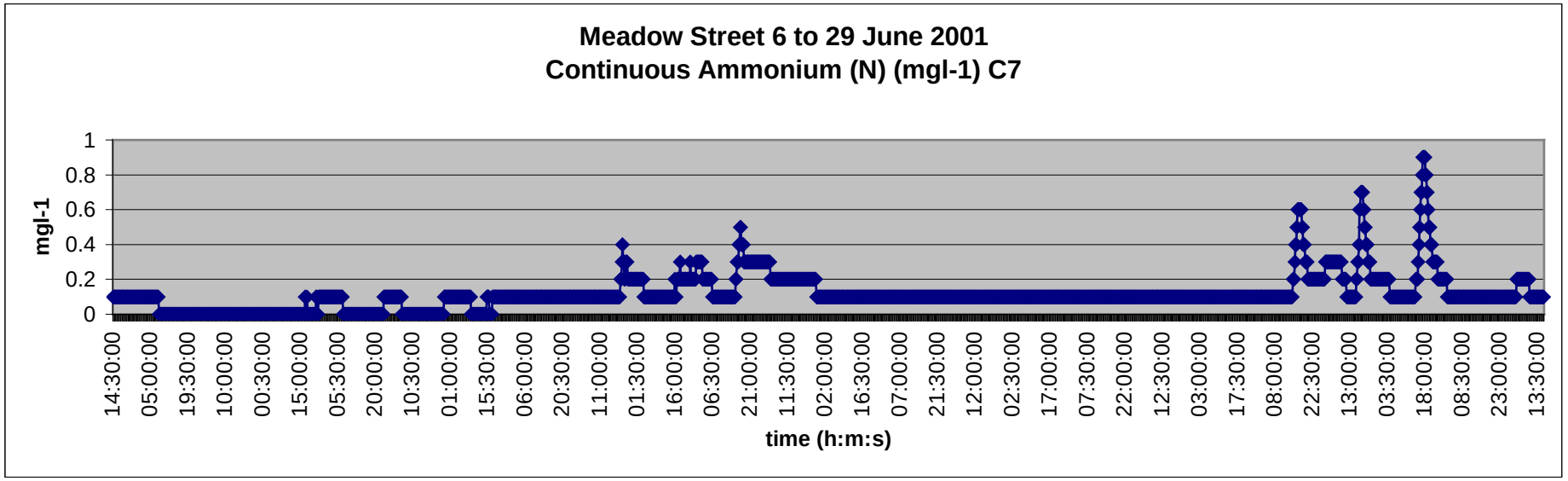


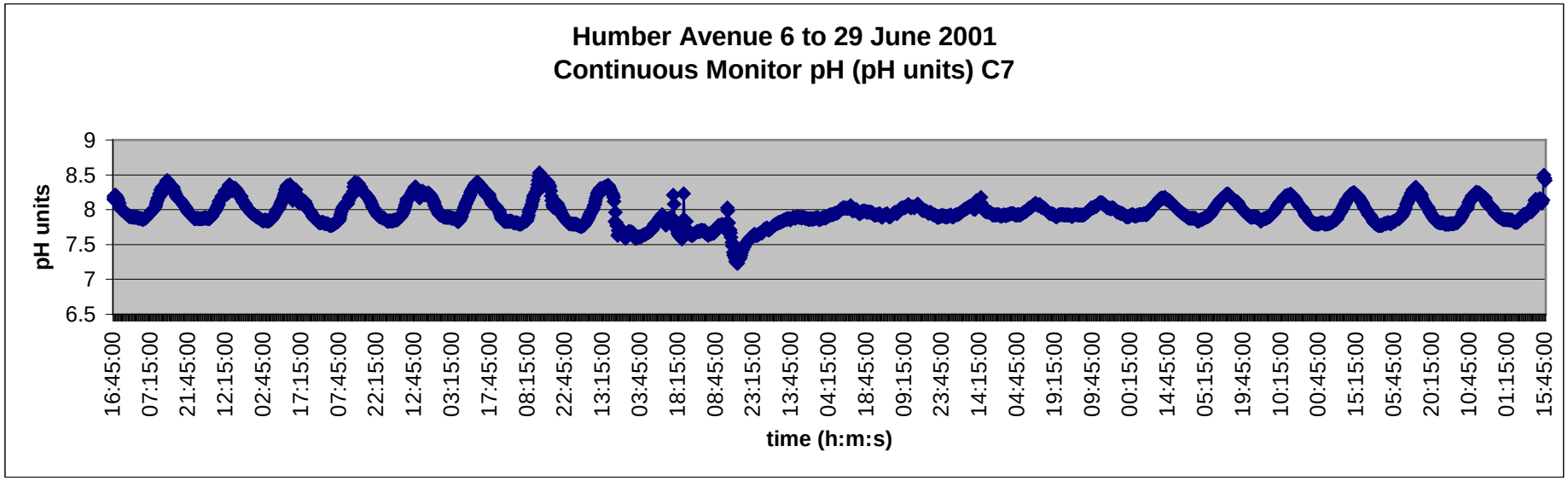


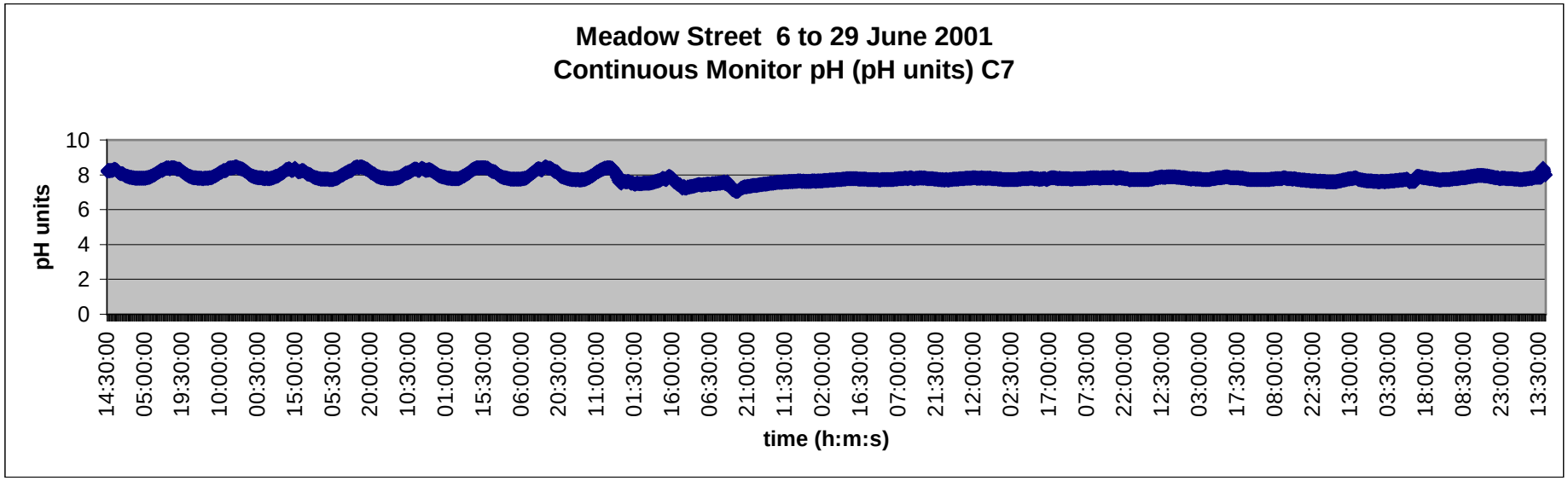

Humber Avenue 6 to 29 June 2001
Continuous DO (% saturation) C7
% saturation
160
140
120
100
80
60
40
20
0
16:45:00
06:15:00
19:45:00
09:15:00
22:45:00
12:15:00
01:45:00
15:15:00
04:45:00
18:15:00
07:45:00
21:15:00
10:45:00
00:15:00
13:45:00
03:15:00
16:45:00
06:15:00
19:45:00
09:15:00
22:45:00
12:15:00
01:45:00
15:15:00
04:45:00
18:15:00
07:45:00
21:15:00
10:45:00
00:15:00
13:45:00
03:15:00
16:45:00
06:15:00
19:45:00
09:15:00
22:45:00
12:15:00
01:45:00
15:15:00
04:45:00
time (h:m:s)

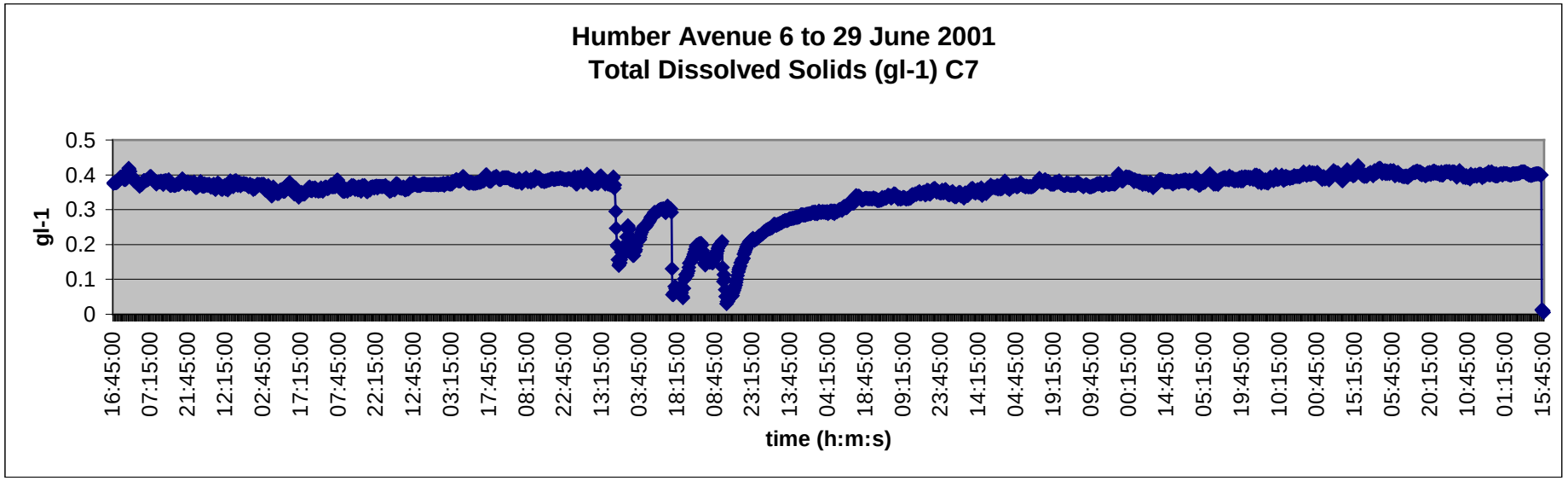

Meadow Street 6 to 29 June 2001
Continuous DO (% saturation) C7
% saturation
160
140
120
100
80
60
40
20
0
14:30:00
04:00:00
17:30:00
07:00:00
20:30:00
10:00:00
23:30:00
13:00:00
02:30:00
16:00:00
05:30:00
19:00:00
08:30:00
22:00:00
11:30:00
01:00:00
14:30:00
04:00:00
17:30:00
07:00:00
20:30:00
10:00:00
23:30:00
13:00:00
02:30:00
16:00:00
05:30:00
19:00:00
08:30:00
22:00:00
11:30:00
01:00:00
14:30:00
04:00:00
17:30:00
07:00:00
20:30:00
10:00:00
23:30:00
13:00:00
02:30:00
time (h:m:s)

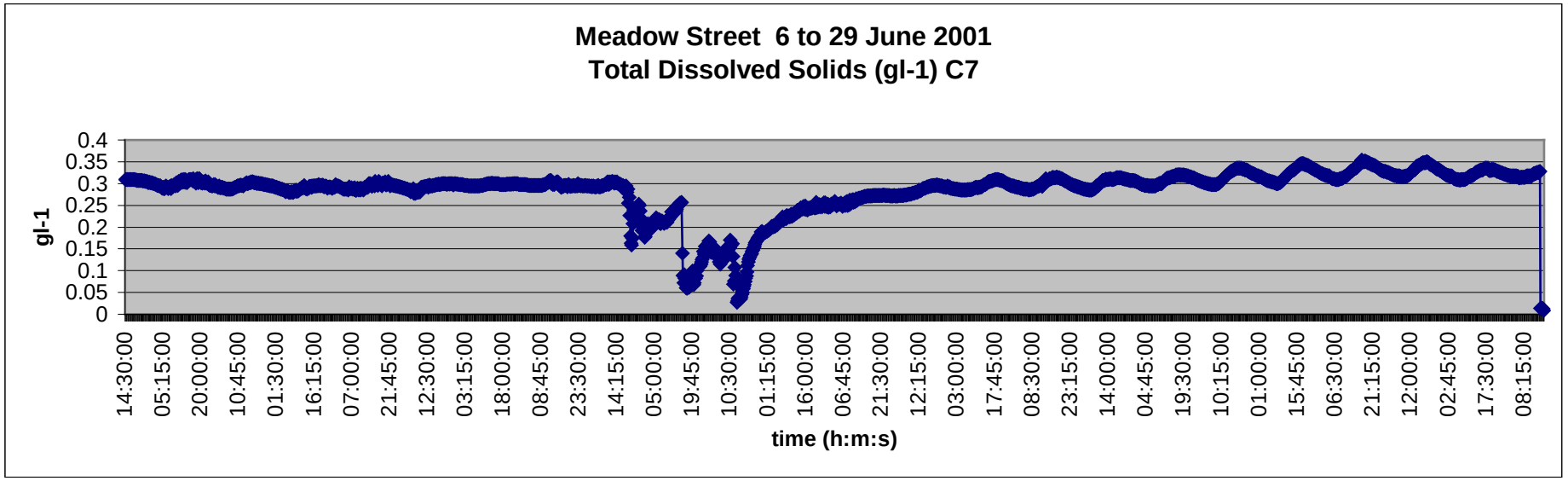

Humber Avenue 6 to 29 June 2001
Continuous Ammonium (N) (mgl-1) C7
mgl-1
1.4
1.2
1
0.8
0.6
0.4
0.2
0
16:45:00
07:15:00
21:45:00
12:15:00
02:45:00
17:15:00
07:45:00
22:15:00
12:45:00
03:15:00
17:45:00
08:15:00
22:45:00
13:15:00
03:45:00
18:15:00
08:45:00
23:15:00
13:45:00
04:15:00
18:45:00
09:15:00
23:45:00
14:15:00
04:45:00
19:15:00
09:45:00
00:15:00
14:45:00
05:15:00
19:45:00
10:15:00
00:45:00
15:15:00
05:45:00
20:15:00
10:45:00
01:15:00
15:45:00
time (h:m:s)

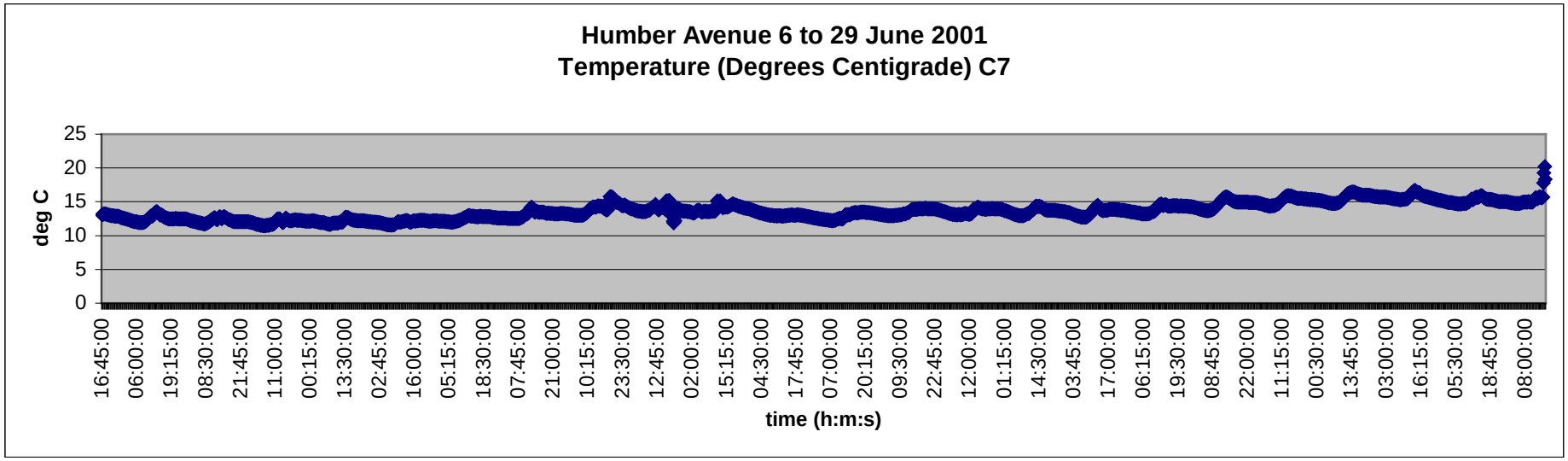

Meadow Street 6 to 29 June 2001
Continuous Ammonium (N) (mgl-1) C7
mgl-1
1
0.8
0.6
0.4
0.2
0
14:30:00
05:00:00
19:30:00
10:00:00
00:30:00
15:00:00
05:30:00
20:00:00
10:30:00
01:00:00
15:30:00
06:00:00
20:30:00
11:00:00
01:30:00
16:00:00
06:30:00
21:00:00
11:30:00
02:00:00
16:30:00
07:00:00
21:30:00
12:00:00
02:30:00
17:00:00
07:30:00
22:00:00
12:30:00
03:00:00
17:30:00
08:00:00
22:30:00
13:00:00
03:30:00
18:00:00
08:30:00
23:00:00
13:30:00
time (h:m:s)

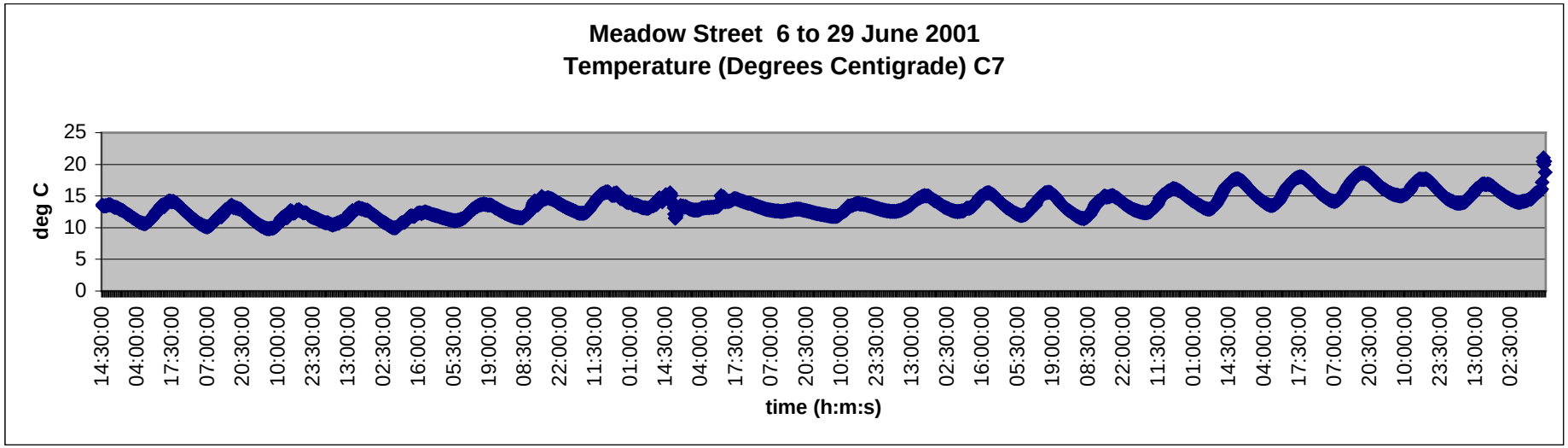

Humber Avenue 6 to 29 June 2001
Continuous Monitor pH (pH units) C7
pH units
9
8.5
8
7.5
7
6.5
16:45:00
07:15:00
21:45:00
12:15:00
02:45:00
17:15:00
07:45:00
22:15:00
12:45:00
03:15:00
17:45:00
08:15:00
22:45:00
13:15:00
03:45:00
18:15:00
08:45:00
23:15:00
13:45:00
04:15:00
18:45:00
09:15:00
23:45:00
14:15:00
04:45:00
19:15:00
09:45:00
00:15:00
14:45:00
05:15:00
19:45:00
10:15:00
00:45:00
15:15:00
05:45:00
20:15:00
10:45:00
01:15:00
15:45:00
time (h:m:s)


Meadow Street 6 to 29 June 2001
Continuous Monitor pH (pH units) C7
pH units
10
8
6
4
2
0
14:30:00
05:00:00
19:30:00
10:00:00
00:30:00
15:00:00
05:30:00
20:00:00
10:30:00
01:00:00
15:30:00
06:00:00
20:30:00
11:00:00
01:30:00
16:00:00
06:30:00
21:00:00
11:30:00
02:00:00
16:30:00
07:00:00
21:30:00
12:00:00
02:30:00
17:00:00
07:30:00
22:00:00
12:30:00
03:00:00
17:30:00
08:00:00
22:30:00
13:00:00
03:30:00
18:00:00
08:30:00
23:00:00
13:30:00
time (h:m:s)

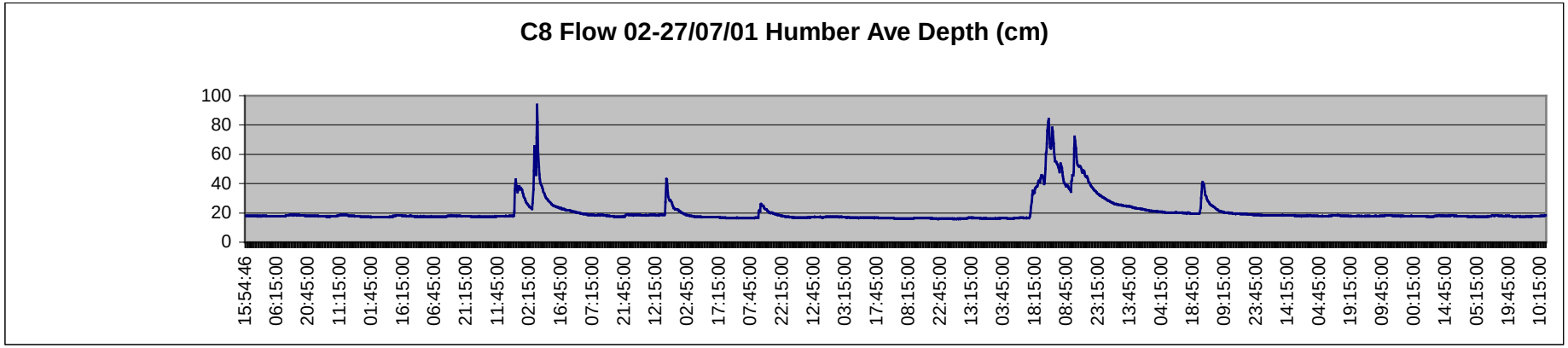

Humber Avenue 6 to 29 June 2001
Total Dissolved Solids (gl-1) C7
gl-1
0.5
0.4
0.3
0.2
0.1
0
16:45:00
07:15:00
21:45:00
12:15:00
02:45:00
17:15:00
07:45:00
22:15:00
12:45:00
03:15:00
17:45:00
08:15:00
22:45:00
13:15:00
03:45:00
18:15:00
08:45:00
23:15:00
13:45:00
04:15:00
18:45:00
09:15:00
23:45:00
14:15:00
04:45:00
19:15:00
09:45:00
00:15:00
14:45:00
05:15:00
19:45:00
10:15:00
00:45:00
15:15:00
05:45:00
20:15:00
10:45:00
01:15:00
15:45:00
time (h:m:s)

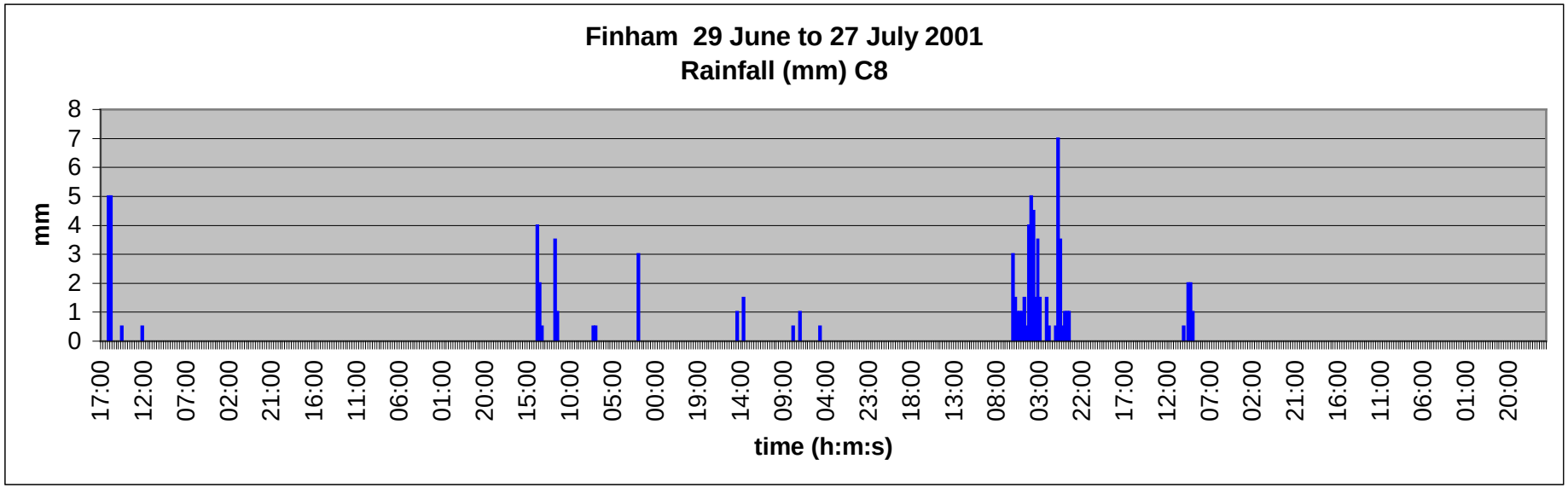

Meadow Street 6 to 29 June 2001
Total Dissolved Solids (gl-1) C7
gl-1
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
14:30:00
05:15:00
20:00:00
10:45:00
01:30:00
16:15:00
07:00:00
21:45:00
12:30:00
03:15:00
18:00:00
08:45:00
23:30:00
14:15:00
05:00:00
19:45:00
10:30:00
01:15:00
16:00:00
06:45:00
21:30:00
12:15:00
03:00:00
17:45:00
08:30:00
23:15:00
14:00:00
04:45:00
19:30:00
10:15:00
01:00:00
15:45:00
06:30:00
21:15:00
12:00:00
02:45:00
17:30:00
08:15:00
time (h:m:s)

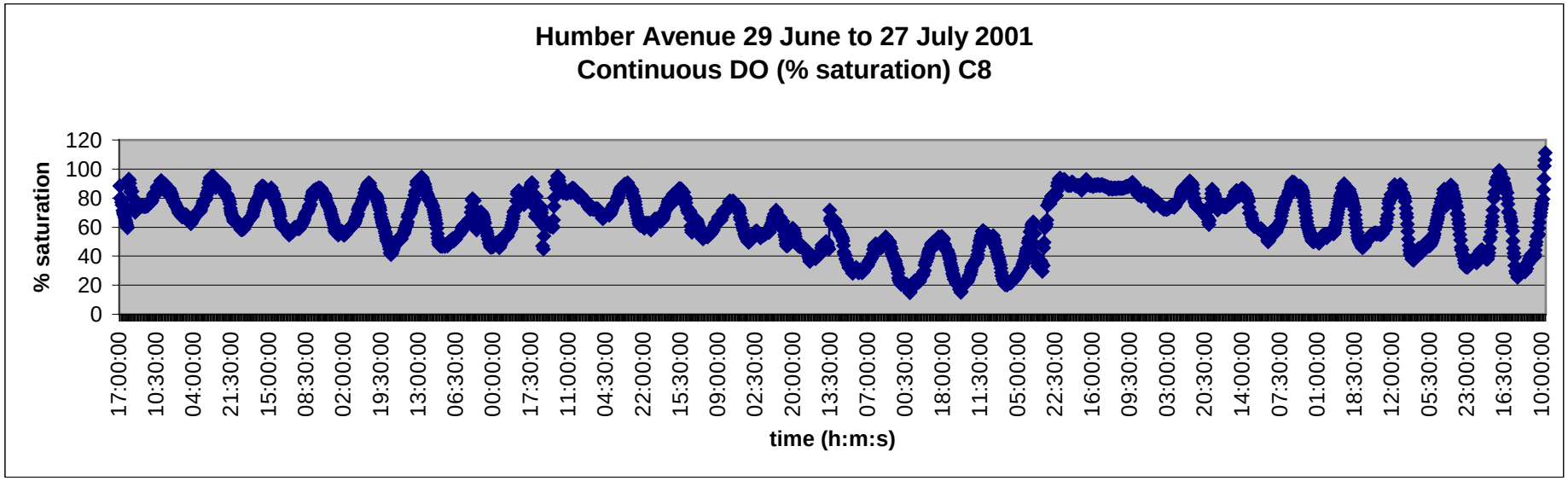

Humber Avenue 6 to 29 June 2001
Temperature (Degrees Centigrade) C7
deg C
25
20
15
10
5
0
16:45:00
06:00:00
19:15:00
08:30:00
21:45:00
11:00:00
00:15:00
13:30:00
02:45:00
16:00:00
05:15:00
18:30:00
07:45:00
21:00:00
10:15:00
23:30:00
12:45:00
02:00:00
15:15:00
04:30:00
17:45:00
07:00:00
20:15:00
09:30:00
22:45:00
12:00:00
01:15:00
14:30:00
03:45:00
17:00:00
06:15:00
19:30:00
08:45:00
22:00:00
11:15:00
00:30:00
13:45:00
03:00:00
16:15:00
05:30:00
18:45:00
08:00:00
time (h:m:s)

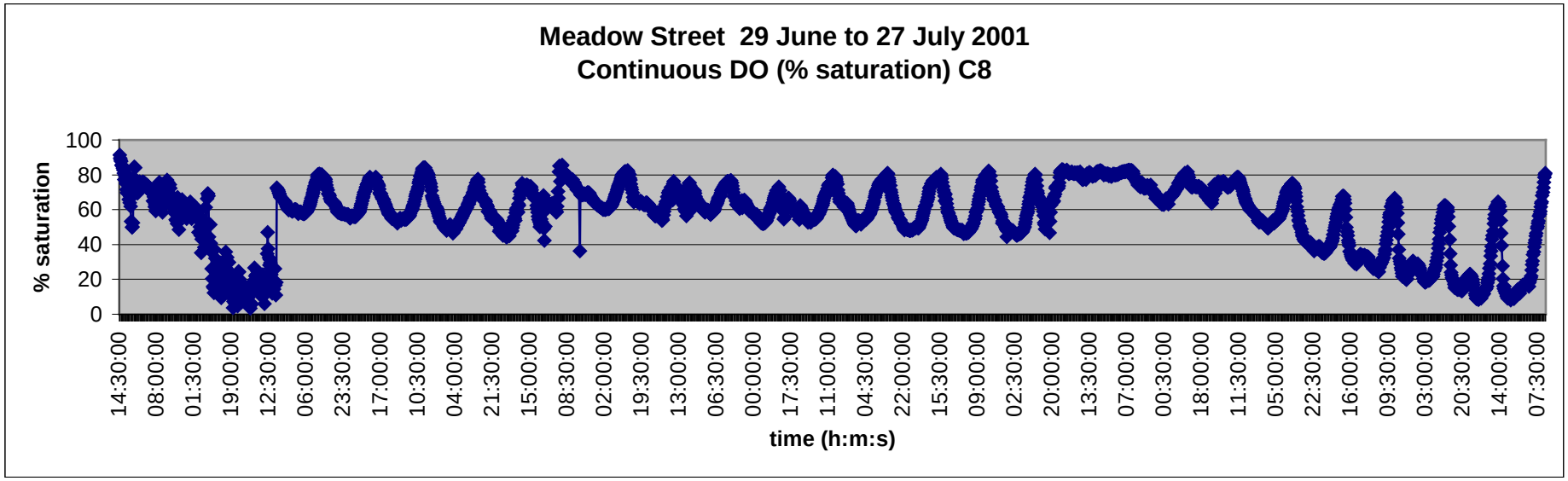

Meadow Street 6 to 29 June 2001
Temperature (Degrees Centigrade) C7
deg C
25
20
15
10
5
0
14:30:00
04:00:00
17:30:00
07:00:00
20:30:00
10:00:00
23:30:00
13:00:00
02:30:00
16:00:00
05:30:00
19:00:00
08:30:00
22:00:00
11:30:00
01:00:00
14:30:00
04:00:00
17:30:00
07:00:00
20:30:00
10:00:00
23:30:00
13:00:00
02:30:00
16:00:00
05:30:00
19:00:00
08:30:00
22:00:00
11:30:00
01:00:00
14:30:00
04:00:00
17:30:00
07:00:00
20:30:00
10:00:00
23:30:00
13:00:00
02:30:00
time (h:m:s)

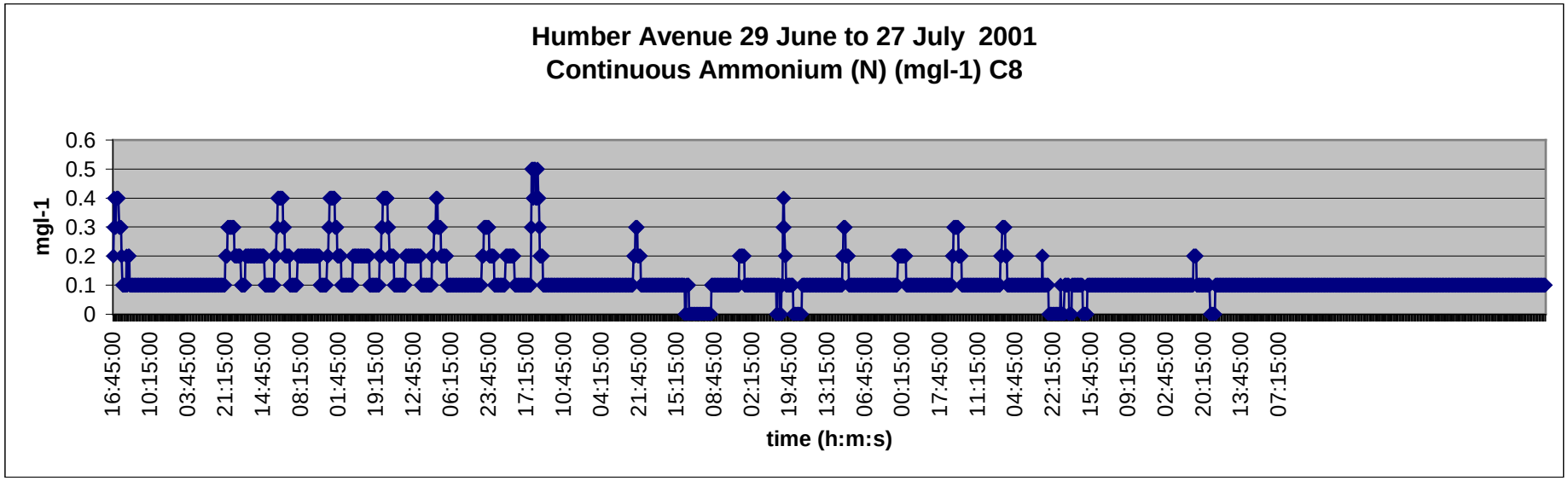
C8 Depth and Continuous monitors

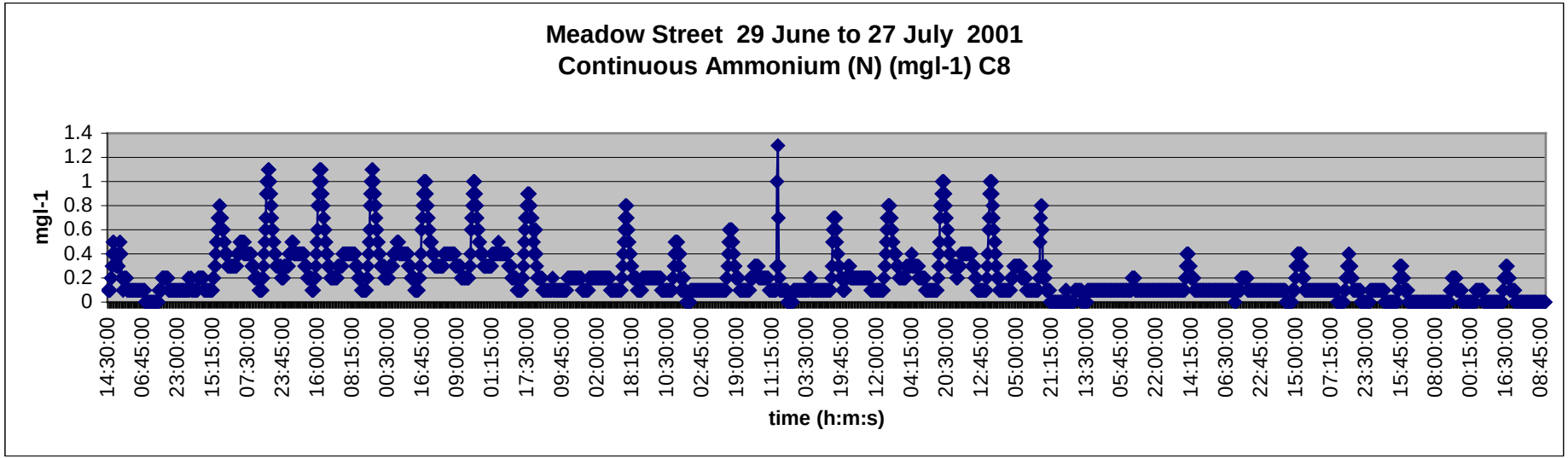


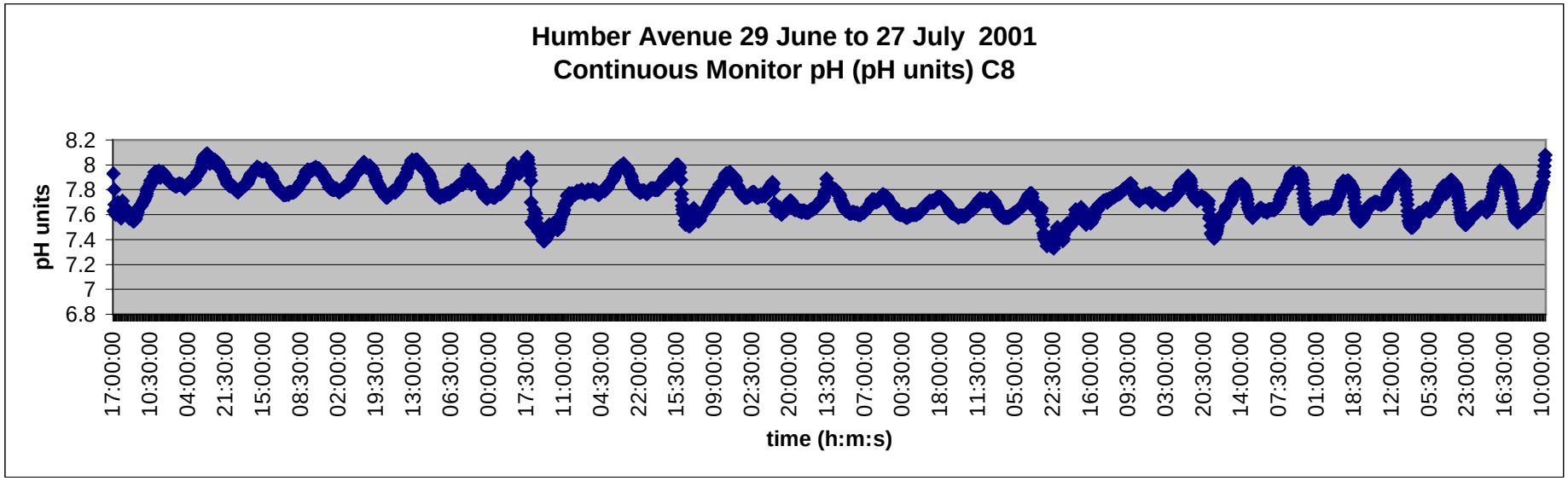


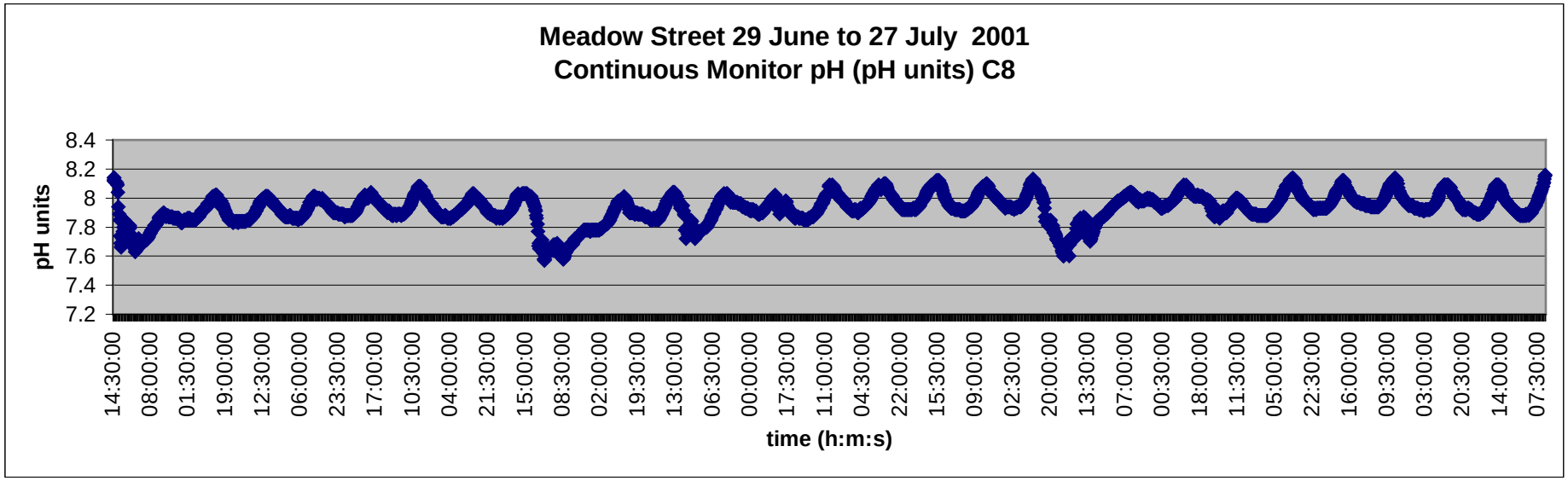

Humber Avenue 29 June to 27 July 2001
Continuous DO (% saturation) C8
% saturation
120
100
80
60
40
20
0
17:00:00
10:30:00
04:00:00
21:30:00
15:00:00
08:30:00
02:00:00
19:30:00
13:00:00
06:30:00
00:00:00
17:30:00
11:00:00
04:30:00
22:00:00
15:30:00
09:00:00
02:30:00
20:00:00
13:30:00
07:00:00
00:30:00
18:00:00
11:30:00
05:00:00
22:30:00
16:00:00
09:30:00
03:00:00
20:30:00
14:00:00
07:30:00
01:00:00
18:30:00
12:00:00
05:30:00
23:00:00
16:30:00
10:00:00
time (h:m:s)

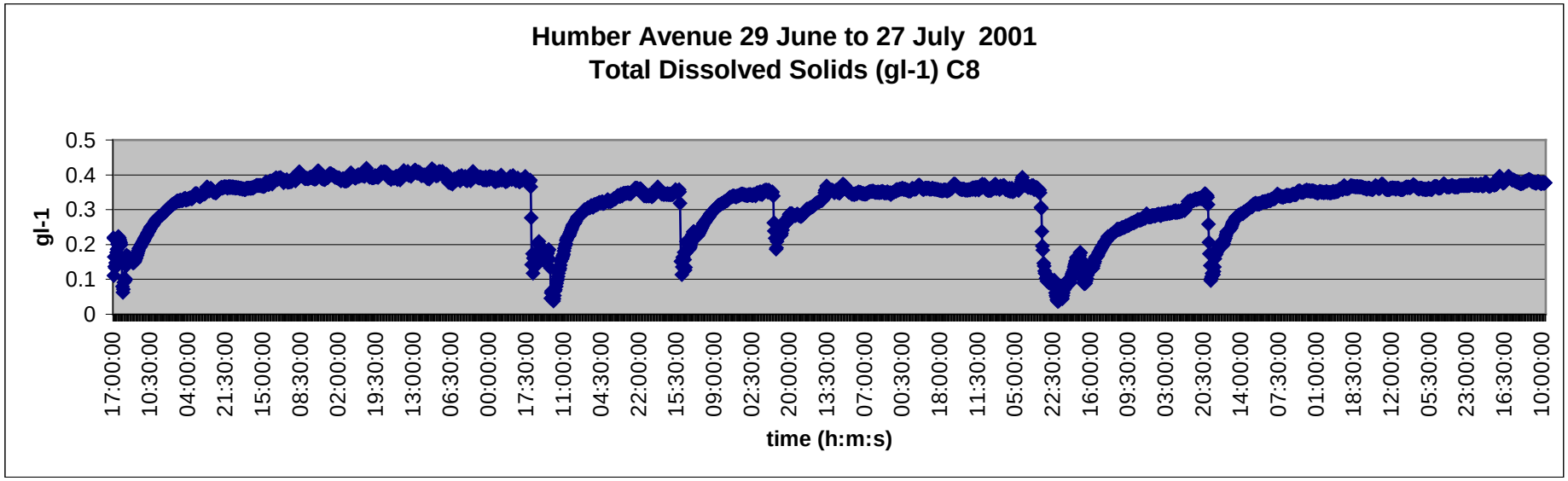

Meadow Street 29 June to 27 July 2001
Continuous DO (% saturation) C8
% saturation
100
80
60
40
20
0
14:30:00
08:00:00
01:30:00
19:00:00
12:30:00
06:00:00
23:30:00
17:00:00
10:30:00
04:00:00
21:30:00
15:00:00
08:30:00
02:00:00
19:30:00
13:00:00
06:30:00
00:00:00
17:30:00
11:00:00
04:30:00
22:00:00
15:30:00
09:00:00
02:30:00
20:00:00
13:30:00
07:00:00
00:30:00
18:00:00
11:30:00
05:00:00
22:30:00
16:00:00
09:30:00
03:00:00
20:30:00
14:00:00
07:30:00
time (h:m:s)

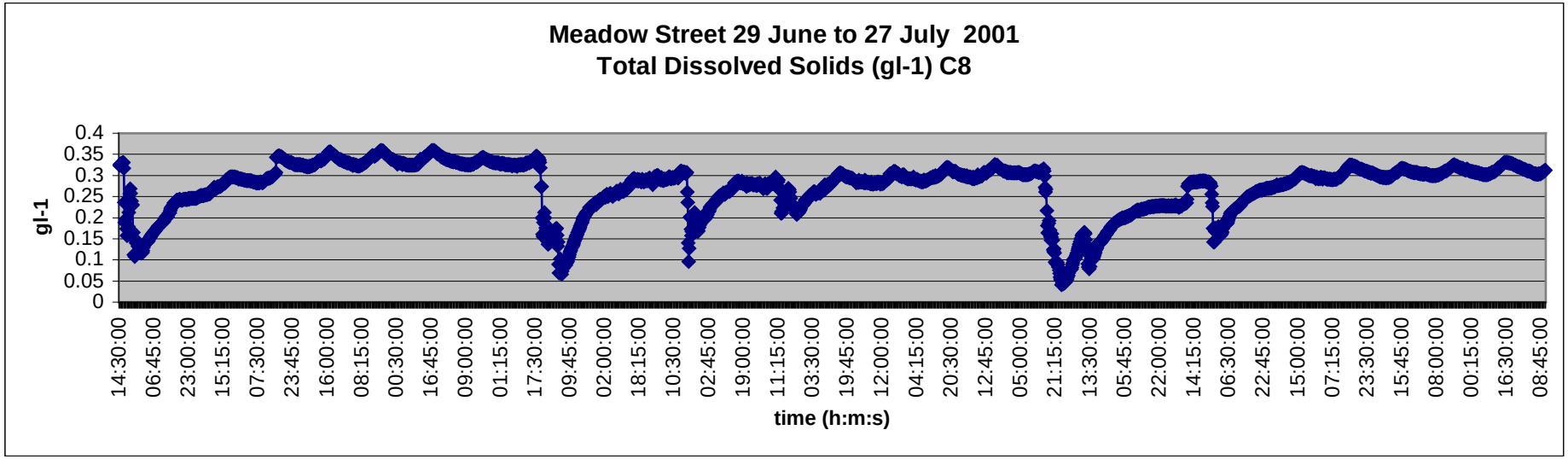

Humber Avenue 29 June to 27 July 2001
Continuous Ammonium (N) (mgl-1) C8
mgl-1
0.6
0.5
0.4
0.3
0.2
0.1
0
16:45:00
10:15:00
03:45:00
21:15:00
14:45:00
08:15:00
01:45:00
19:15:00
12:45:00
06:15:00
23:45:00
17:15:00
10:45:00
04:15:00
21:45:00
15:15:00
08:45:00
02:15:00
19:45:00
13:15:00
06:45:00
00:15:00
17:45:00
11:15:00
04:45:00
22:15:00
15:45:00
09:15:00
02:45:00
20:15:00
13:45:00
07:15:00
time (h:m:s)

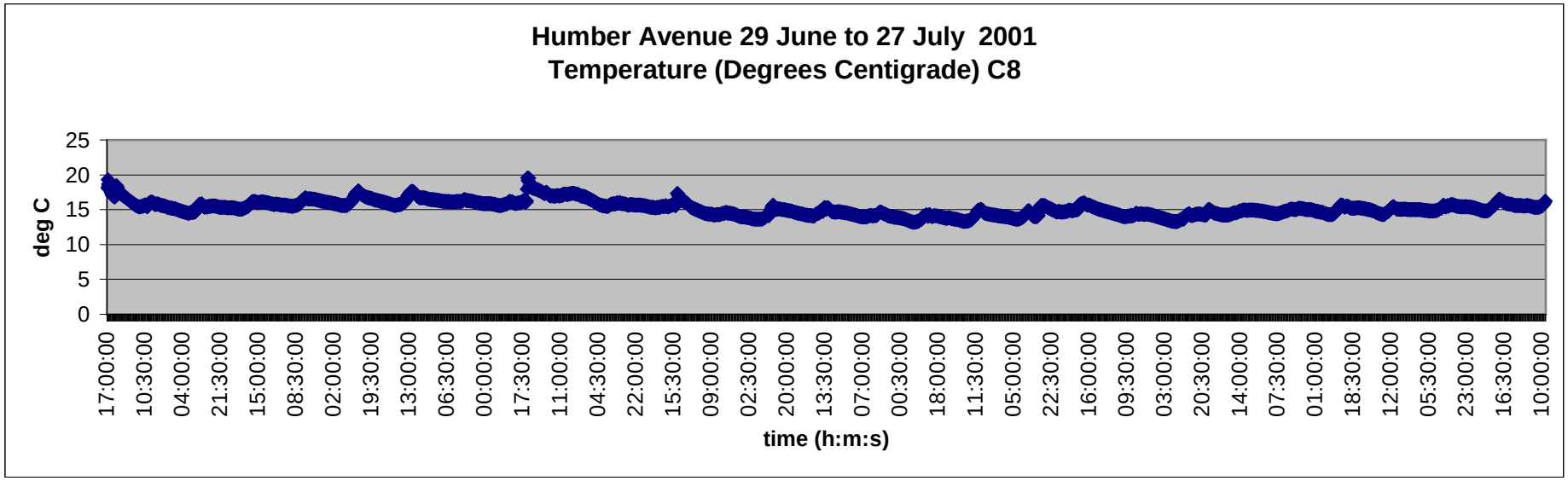

Meadow Street 29 June to 27 July 2001
Continuous Ammonium (N) (mgl-1) C8
mgl-1
1.4
1.2
1
0.8
0.6
0.4
0.2
0
14:30:00
06:45:00
23:00:00
15:15:00
07:30:00
23:45:00
16:00:00
08:15:00
00:30:00
16:45:00
09:00:00
01:15:00
17:30:00
09:45:00
02:00:00
18:15:00
10:30:00
02:45:00
19:00:00
11:15:00
03:30:00
19:45:00
12:00:00
04:15:00
20:30:00
12:45:00
05:00:00
21:15:00
13:30:00
05:45:00
22:00:00
14:15:00
06:30:00
22:45:00
15:00:00
07:15:00
23:30:00
15:45:00
08:00:00
00:15:00
16:30:00
08:45:00
time (h:m:s)

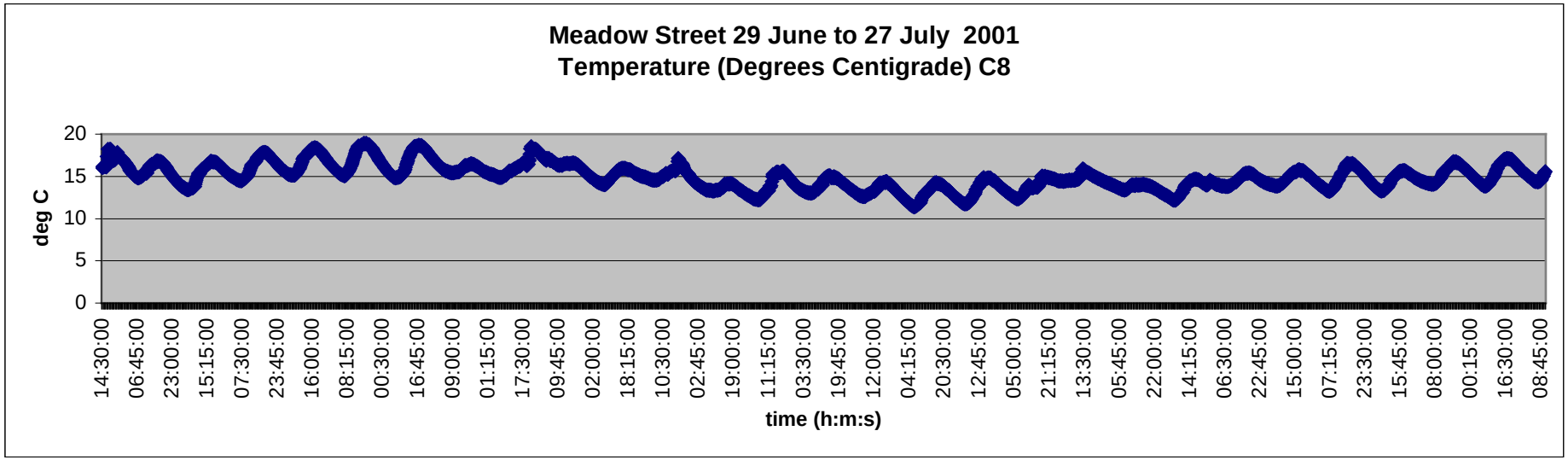

Humber Avenue 29 June to 27 July 2001
Continuous Monitor pH (pH units) C8
pH units
8.2
8
7.8
7.6
7.4
7.2
7
6.8
17:00:00
10:30:00
04:00:00
21:30:00
15:00:00
08:30:00
02:00:00
19:30:00
13:00:00
06:30:00
00:00:00
17:30:00
11:00:00
04:30:00
22:00:00
15:30:00
09:00:00
02:30:00
20:00:00
13:30:00
07:00:00
00:30:00
18:00:00
11:30:00
05:00:00
22:30:00
16:00:00
09:30:00
03:00:00
20:30:00
14:00:00
07:30:00
01:00:00
18:30:00
12:00:00
05:30:00
23:00:00
16:30:00
10:00:00
time (h:m:s)


Meadow Street 29 June to 27 July 2001
Continuous Monitor pH (pH units) C8
pH units
8.4
8.2
8
7.8
7.6
7.4
7.2
14:30:00
08:00:00
01:30:00
19:00:00
12:30:00
06:00:00
23:30:00
17:00:00
10:30:00
04:00:00
21:30:00
15:00:00
08:30:00
02:00:00
19:30:00
13:00:00
06:30:00
00:00:00
17:30:00
11:00:00
04:30:00
22:00:00
15:30:00
09:00:00
02:30:00
20:00:00
13:30:00
07:00:00
00:30:00
18:00:00
11:30:00
05:00:00
22:30:00
16:00:00
09:30:00
03:00:00
20:30:00
14:00:00
07:30:00
time (h:m:s)

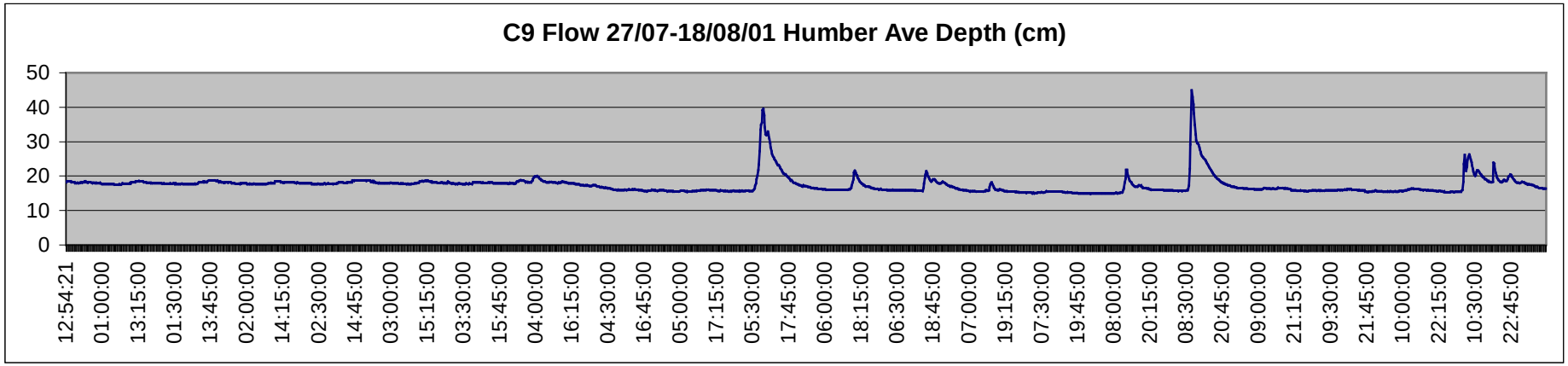

Humber Avenue 29 June to 27 July 2001
Total Dissolved Solids (gl-1) C8
gl-1
0.5
0.4
0.3
0.2
0.1
0
17:00:00
10:30:00
04:00:00
21:30:00
15:00:00
08:30:00
02:00:00
19:30:00
13:00:00
06:30:00
00:00:00
17:30:00
11:00:00
04:30:00
22:00:00
15:30:00
09:00:00
02:30:00
20:00:00
13:30:00
07:00:00
00:30:00
18:00:00
11:30:00
05:00:00
22:30:00
16:00:00
09:30:00
03:00:00
20:30:00
14:00:00
07:30:00
01:00:00
18:30:00
12:00:00
05:30:00
23:00:00
16:30:00
10:00:00
time (h:m:s)

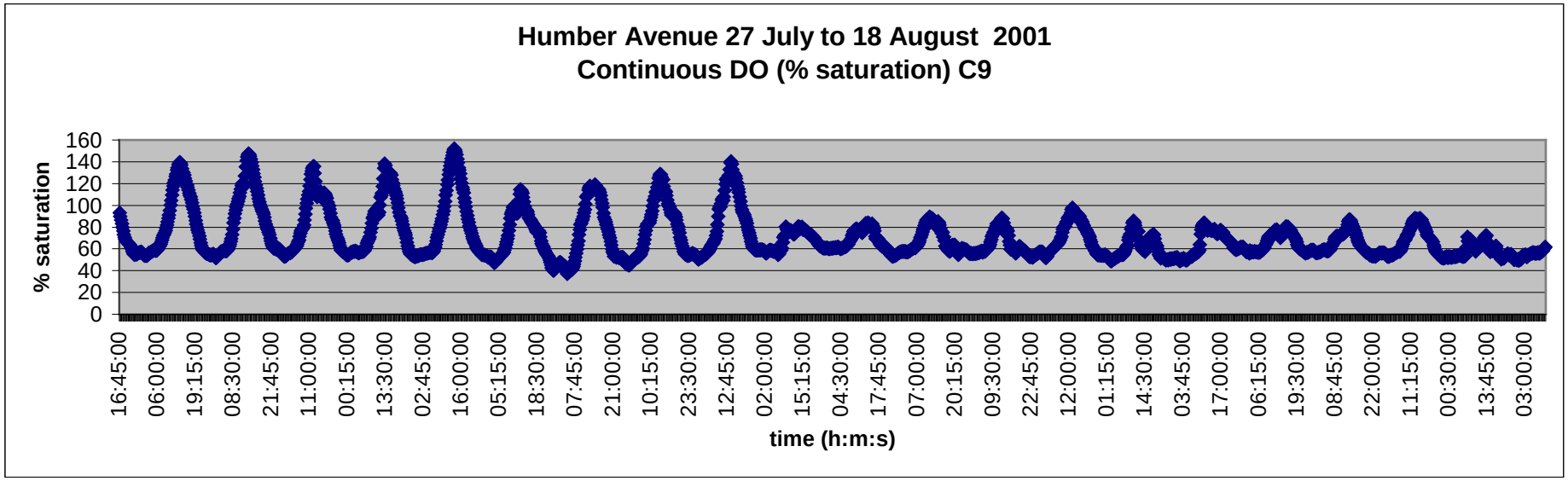

Meadow Street 29 June to 27 July 2001
Total Dissolved Solids (gl-1) C8
gl-1
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
14:30:00
06:45:00
23:00:00
15:15:00
07:30:00
23:45:00
16:00:00
08:15:00
00:30:00
16:45:00
09:00:00
01:15:00
17:30:00
09:45:00
02:00:00
18:15:00
10:30:00
02:45:00
19:00:00
11:15:00
03:30:00
19:45:00
12:00:00
04:15:00
20:30:00
12:45:00
05:00:00
21:15:00
13:30:00
05:45:00
22:00:00
14:15:00
06:30:00
22:45:00
15:00:00
07:15:00
23:30:00
15:45:00
08:00:00
00:15:00
16:30:00
08:45:00
time (h:m:s)

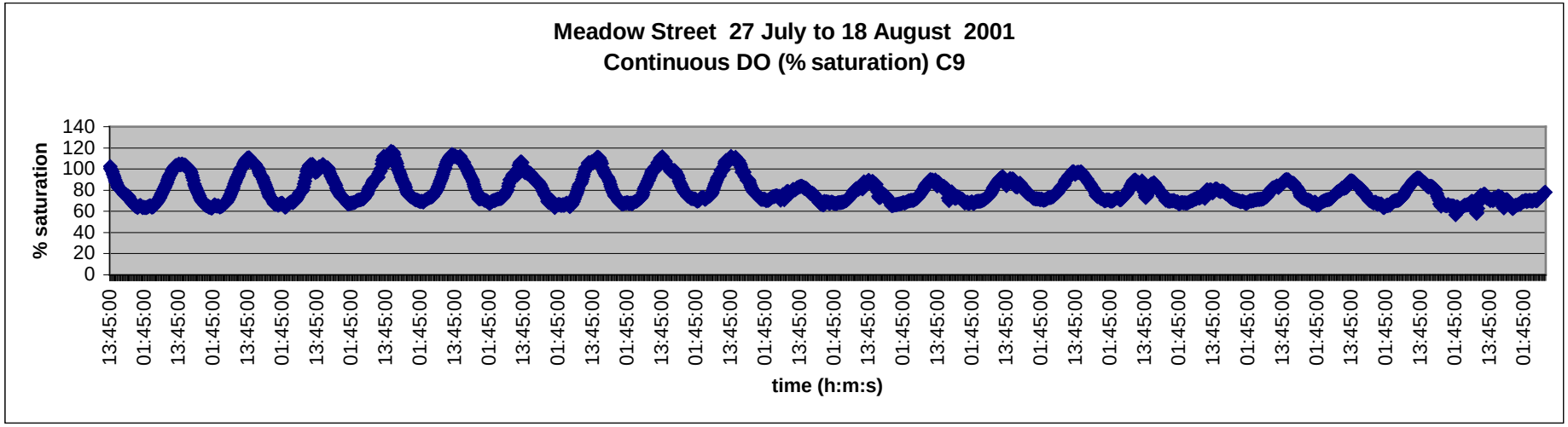

Humber Avenue 29 June to 27 July 2001
Temperature (Degrees Centigrade) C8
deg C
25
20
15
10
5
0
17:00:00
10:30:00
04:00:00
21:30:00
15:00:00
08:30:00
02:00:00
19:30:00
13:00:00
06:30:00
00:00:00
17:30:00
11:00:00
04:30:00
22:00:00
15:30:00
09:00:00
02:30:00
20:00:00
13:30:00
07:00:00
00:30:00
18:00:00
11:30:00
05:00:00
22:30:00
16:00:00
09:30:00
03:00:00
20:30:00
14:00:00
07:30:00
01:00:00
18:30:00
12:00:00
05:30:00
23:00:00
16:30:00
10:00:00
time (h:m:s)

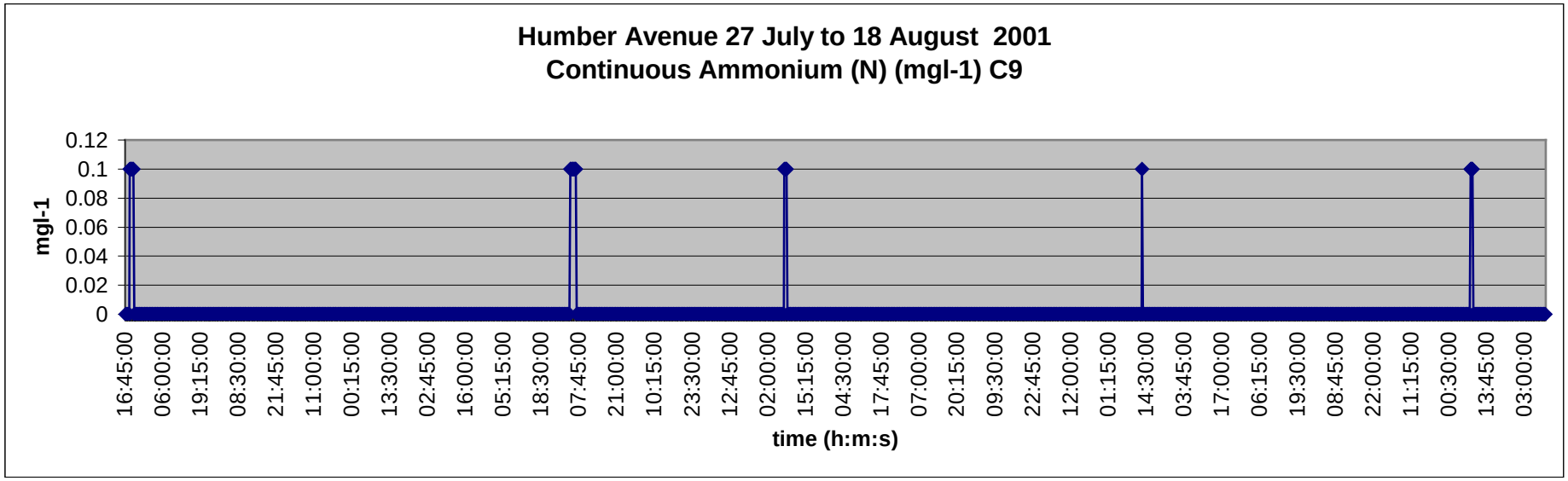

Meadow Street 29 June to 27 July 2001
Temperature (Degrees Centigrade) C8
deg C
20
15
10
5
0
14:30:00
06:45:00
23:00:00
15:15:00
07:30:00
23:45:00
16:00:00
08:15:00
00:30:00
16:45:00
09:00:00
01:15:00
17:30:00
09:45:00
02:00:00
18:15:00
10:30:00
02:45:00
19:00:00
11:15:00
03:30:00
19:45:00
12:00:00
04:15:00
20:30:00
12:45:00
05:00:00
21:15:00
13:30:00
05:45:00
22:00:00
14:15:00
06:30:00
22:45:00
15:00:00
07:15:00
23:30:00
15:45:00
08:00:00
00:15:00
16:30:00
08:45:00
time (h:m:s)

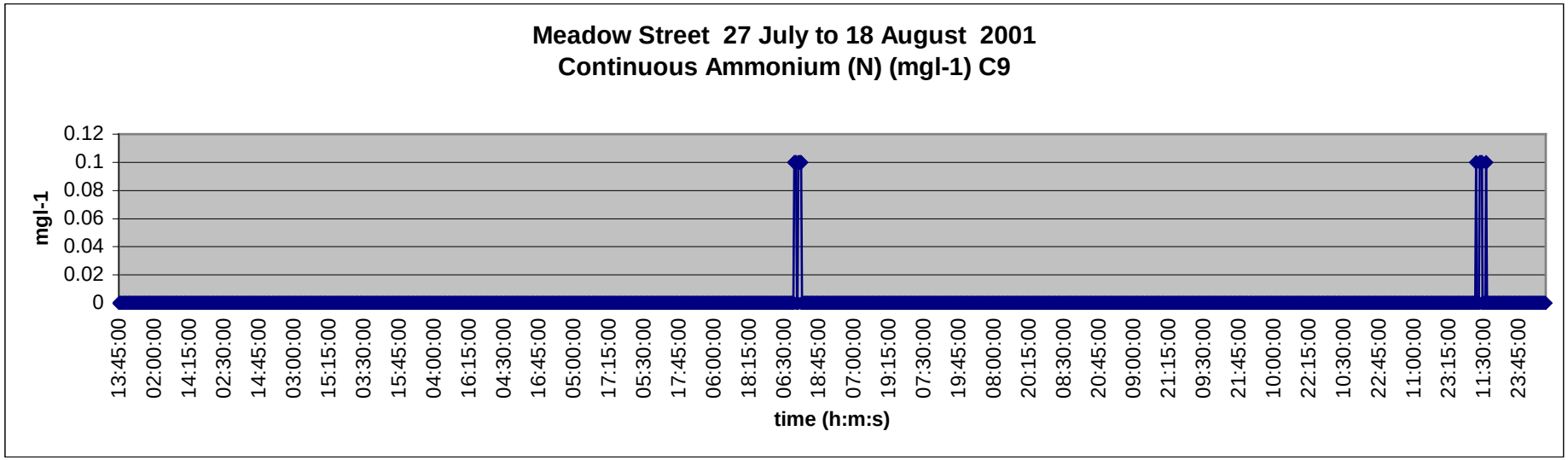
C9 Depth and Continuous monitors

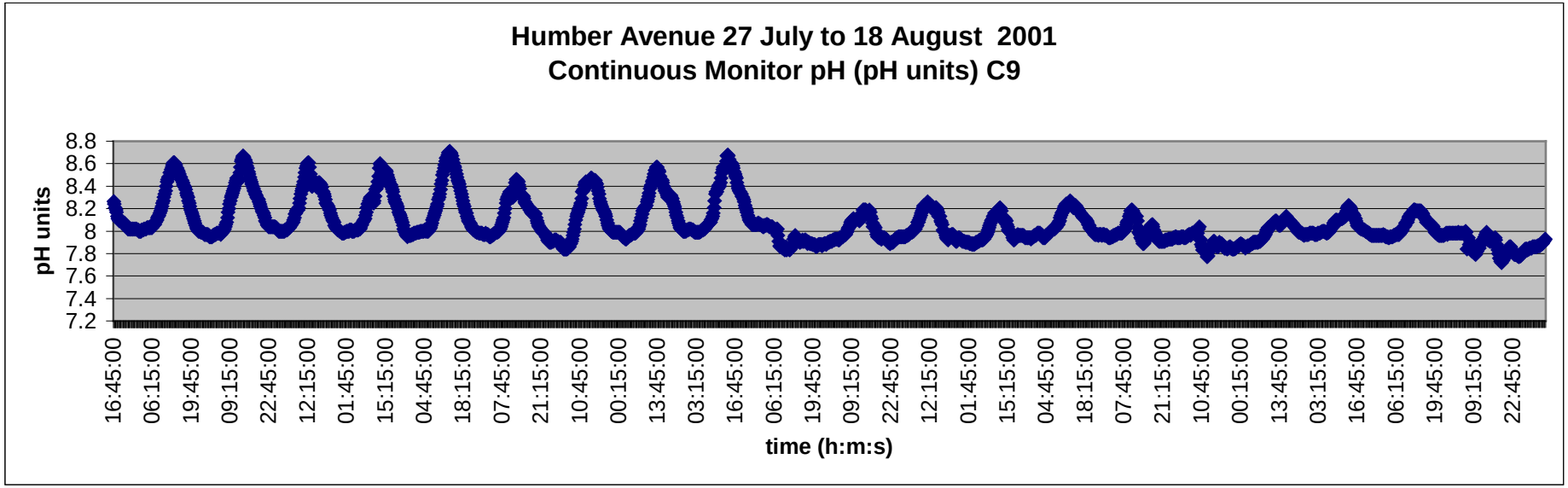


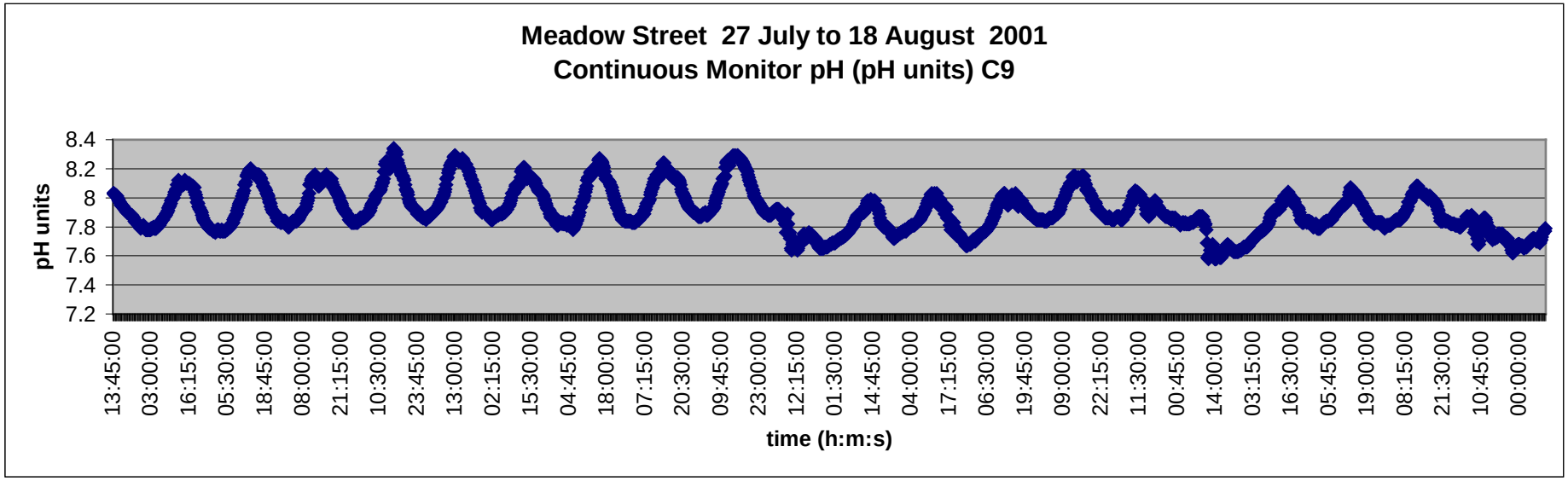


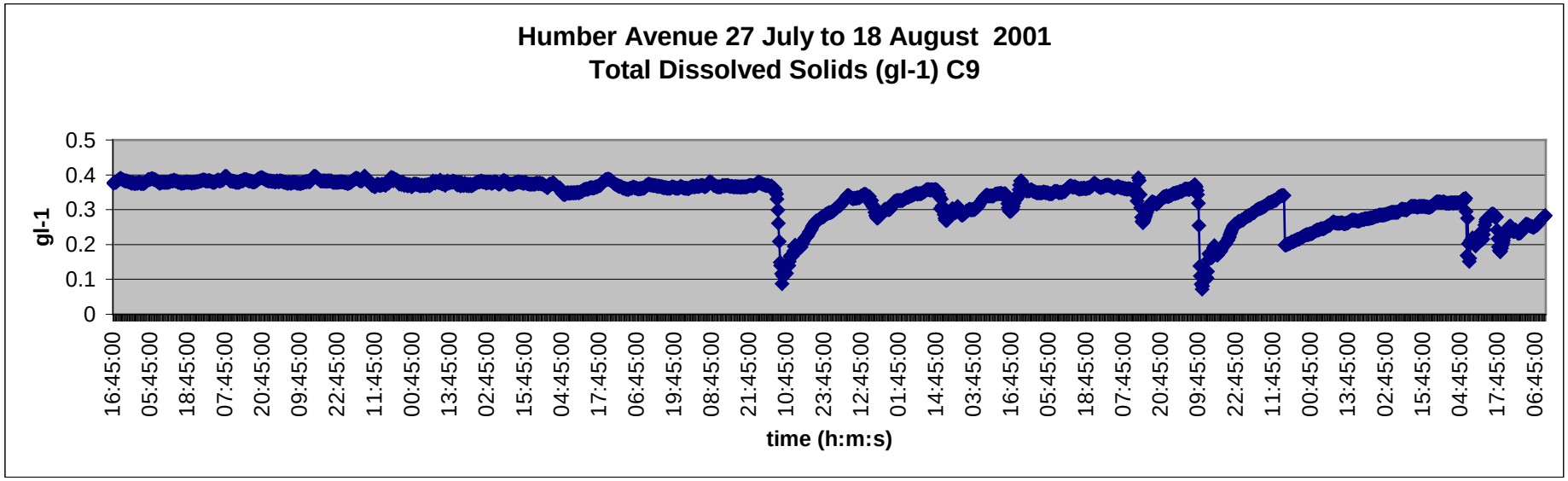

Meadow Street 27 July to 18 August 2001
Continuous DO (% saturation) C9
% saturation
140
120
100
80
60
40
20
0
13:45:00
01:45:00
13:45:00
01:45:00
13:45:00
01:45:00

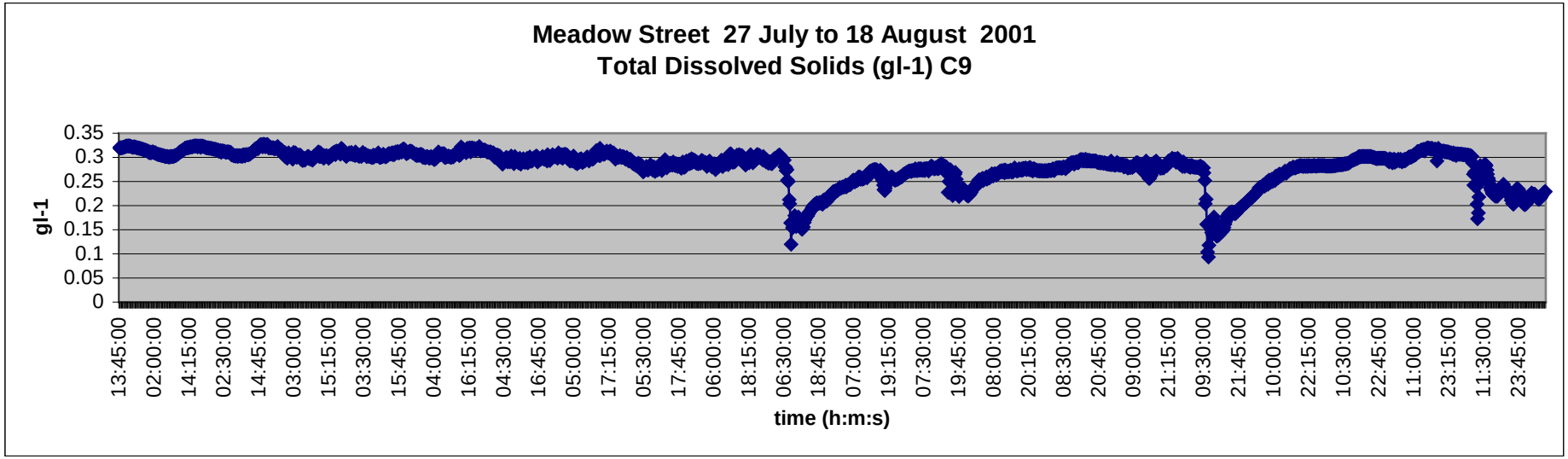

Humber Avenue 27 July to 18 August 2001
Continuous Ammonium (N) (mgl-1) C9
mgl-1
0.12
0.1
0.08
0.06
0.04
0.02
0
16:45:00
06:00:00
19:15:00
08:30:00
21:45:00
11:00:00
00:15:00
13:30:00
02:45:00
16:00:00
05:15:00
18:30:00
07:45:00
21:00:00
10:15:00
23:30:00
12:45:00
02:00:00
15:15:00
04:30:00
17:45:00
07:00:00
20:15:00
09:30:00
22:45:00
12:00:00
01:15:00
14:30:00
03:45:00
17:00:00
06:15:00
19:30:00
08:45:00
22:00:00
11:15:00
00:30:00
13:45:00
03:00:00
time (h:m:s)

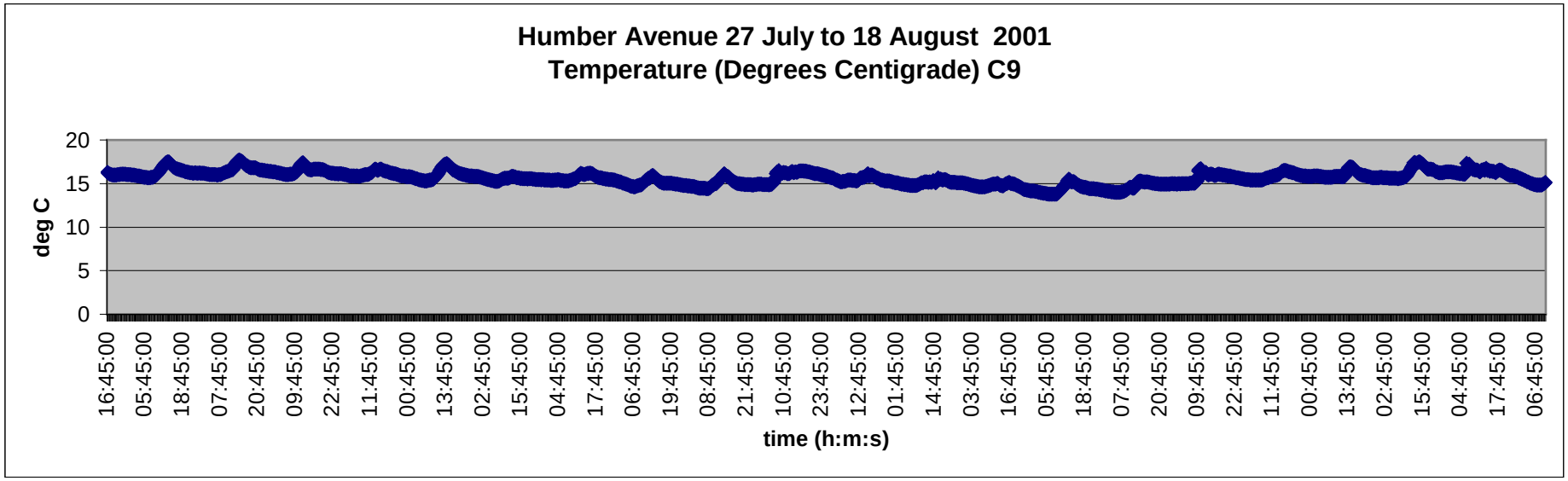

Meadow Street 27 July to 18 August 2001
Continuous Ammonium (N) (mgl-1) C9
mgl-1
0.12
0.1
0.08
0.06
0.04
0.02
0
13:45:00
02:00:00
14:15:00
02:30:00
14:45:00
03:00:00
15:15:00
03:30:00
15:45:00
04:00:00
16:15:00
04:30:00
16:45:00
05:00:00
17:15:00
05:30:00
17:45:00
06:00:00
18:15:00
06:30:00
18:45:00
07:00:00
19:15:00
07:30:00
19:45:00
08:00:00
20:15:00
08:30:00
20:45:00
09:00:00
21:15:00
09:30:00
21:45:00
10:00:00
22:15:00
10:30:00
22:45:00
11:00:00
23:15:00
11:30:00
23:45:00
time (h:m:s)

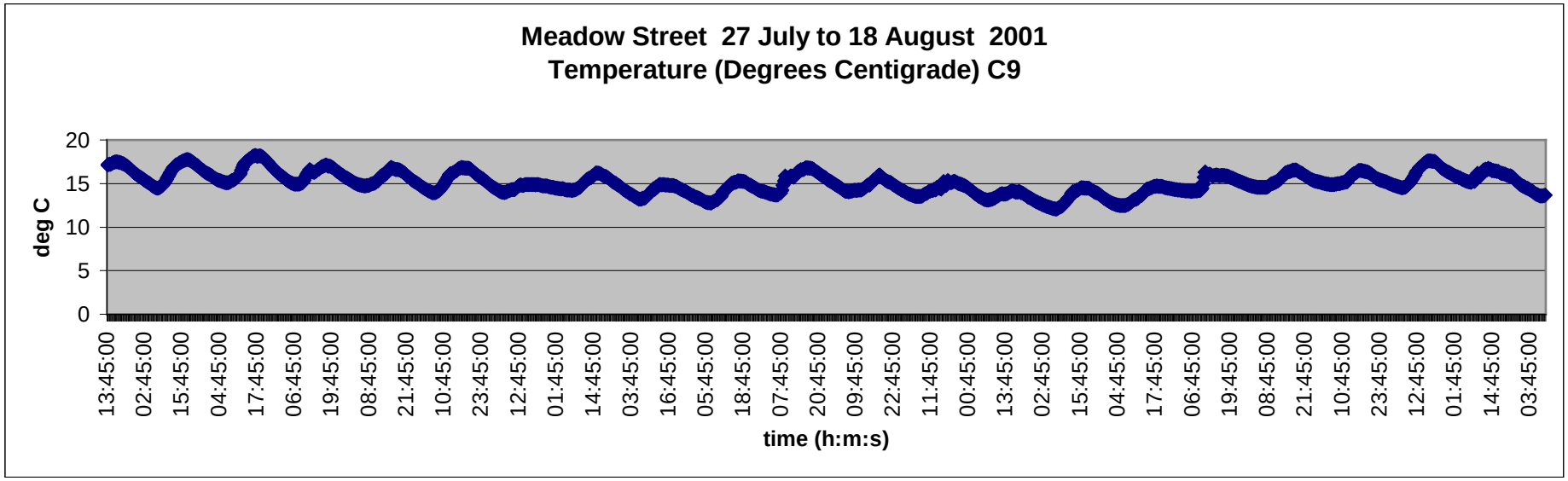

Humber Avenue 27 July to 18 August 2001
Continuous Monitor pH (pH units) C9
pH units
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
16:45:00
06:15:00
19:45:00
09:15:00
22:45:00
12:15:00
01:45:00
15:15:00
04:45:00
18:15:00
07:45:00
21:15:00
10:45:00
00:15:00
13:45:00
03:15:00
16:45:00
06:15:00
19:45:00
09:15:00
22:45:00
12:15:00
01:45:00
15:15:00
04:45:00
18:15:00
07:45:00
21:15:00
10:45:00
00:15:00
13:45:00
03:15:00
16:45:00
06:15:00
19:45:00
09:15:00
22:45:00
time (h:m:s)


Meadow Street 27 July to 18 August 2001
Continuous Monitor pH (pH units) C9
pH units
8.4
8.2
8
7.8
7.6
7.4
7.2
13:45:00
03:00:00
16:15:00
05:30:00
18:45:00
08:00:00
21:15:00
10:30:00
23:45:00
13:00:00
02:15:00
15:30:00
04:45:00
18:00:00
07:15:00
20:30:00
09:45:00
23:00:00
12:15:00
01:30:00
14:45:00
04:00:00
17:15:00
06:30:00
19:45:00
09:00:00
22:15:00
11:30:00
00:45:00
14:00:00
03:15:00
16:30:00
05:45:00
19:00:00
08:15:00
21:30:00
10:45:00
00:00:00
time (h:m:s)

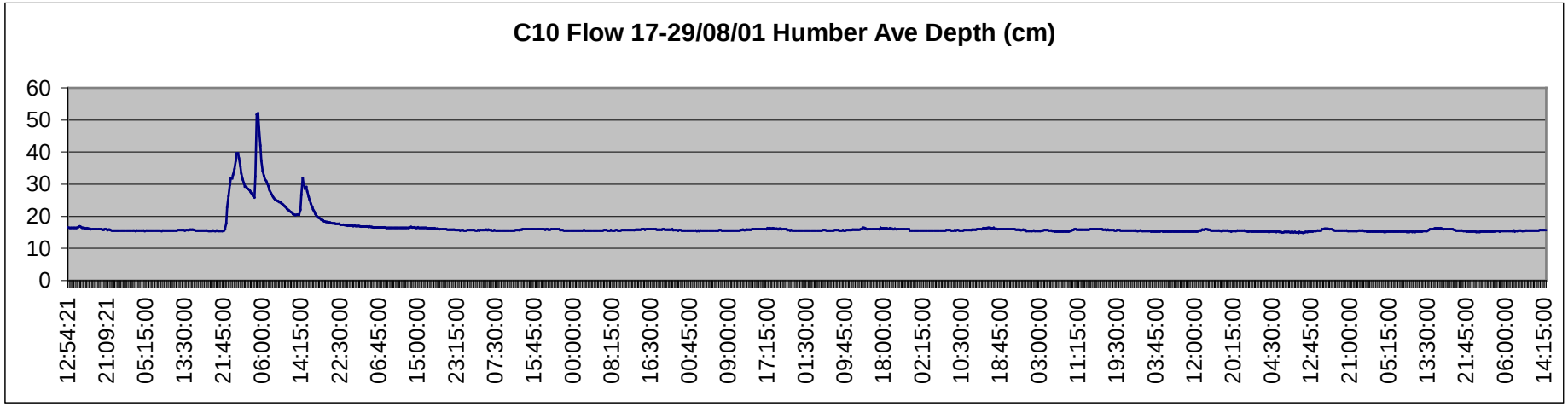

Humber Avenue 27 July to 18 August 2001
Total Dissolved Solids (gl-1) C9
gl-1
0.5
0.4
0.3
0.2
0.1
0
16:45:00
05:45:00
18:45:00
07:45:00
20:45:00
09:45:00
22:45:00
11:45:00
00:45:00
13:45:00
02:45:00
15:45:00
04:45:00
17:45:00
06:45:00
19:45:00
08:45:00
21:45:00
10:45:00
23:45:00
12:45:00
01:45:00
14:45:00
03:45:00
16:45:00
05:45:00
18:45:00
07:45:00
20:45:00
09:45:00
22:45:00
11:45:00
00:45:00
13:45:00
02:45:00
15:45:00
04:45:00
17:45:00
06:45:00
time (h:m:s)

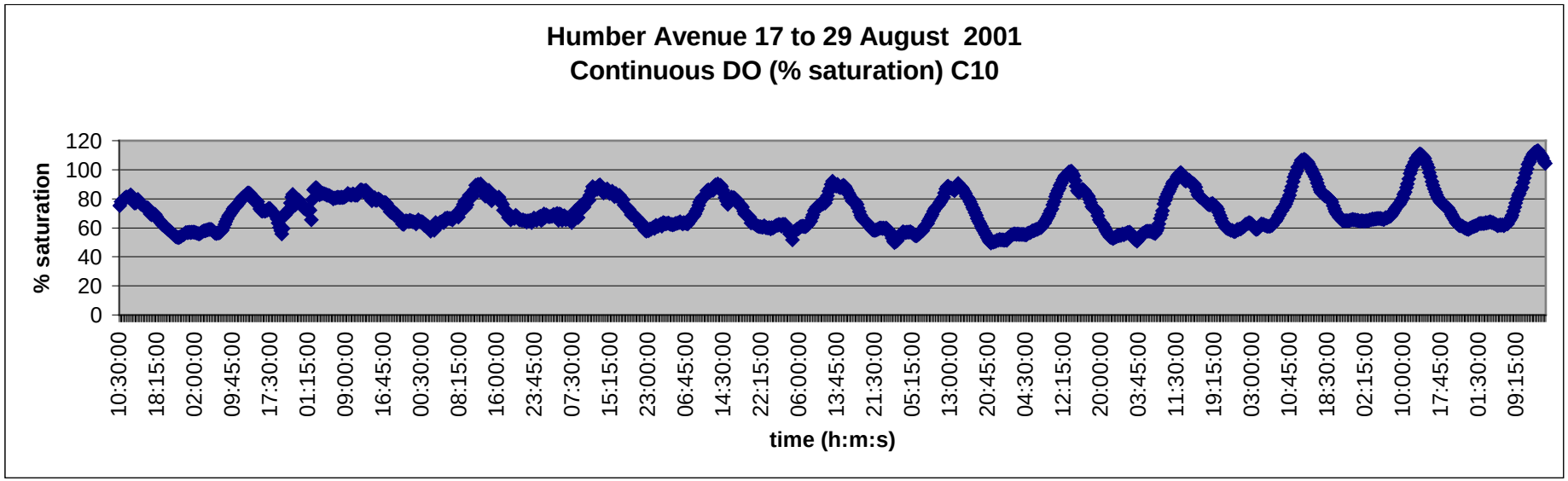

Meadow Street 27 July to 18 August 2001
Total Dissolved Solids (gl-1) C9
gl-1
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
13:45:00
02:00:00
14:15:00
02:30:00
14:45:00
03:00:00
15:15:00
03:30:00
15:45:00
04:00:00
16:15:00
04:30:00
16:45:00
05:00:00
17:15:00
05:30:00
17:45:00
06:00:00
18:15:00
06:30:00
18:45:00
07:00:00
19:15:00
07:30:00
19:45:00
08:00:00
20:15:00
08:30:00
20:45:00
09:00:00
21:15:00
09:30:00
21:45:00
10:00:00
22:15:00
10:30:00
22:45:00
11:00:00
23:15:00
11:30:00
23:45:00
time (h:m:s)

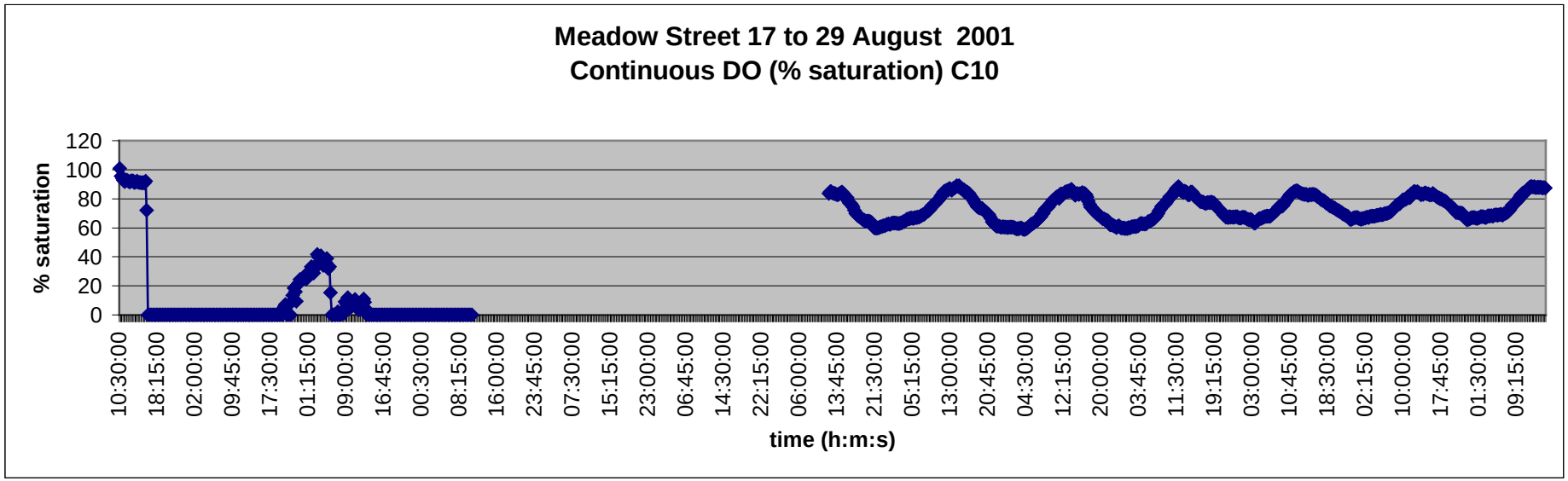

Humber Avenue 27 July to 18 August 2001
Temperature (Degrees Centigrade) C9
deg C
20
15
10
5
0
16:45:00
05:45:00
18:45:00
07:45:00
20:45:00
09:45:00
22:45:00
11:45:00
00:45:00
13:45:00
02:45:00
15:45:00
04:45:00
17:45:00
06:45:00
19:45:00
08:45:00
21:45:00
10:45:00
23:45:00
12:45:00
01:45:00
14:45:00
03:45:00
16:45:00
05:45:00
18:45:00
07:45:00
20:45:00
09:45:00
22:45:00
11:45:00
00:45:00
13:45:00
02:45:00
15:45:00
04:45:00
17:45:00
06:45:00
time (h:m:s)

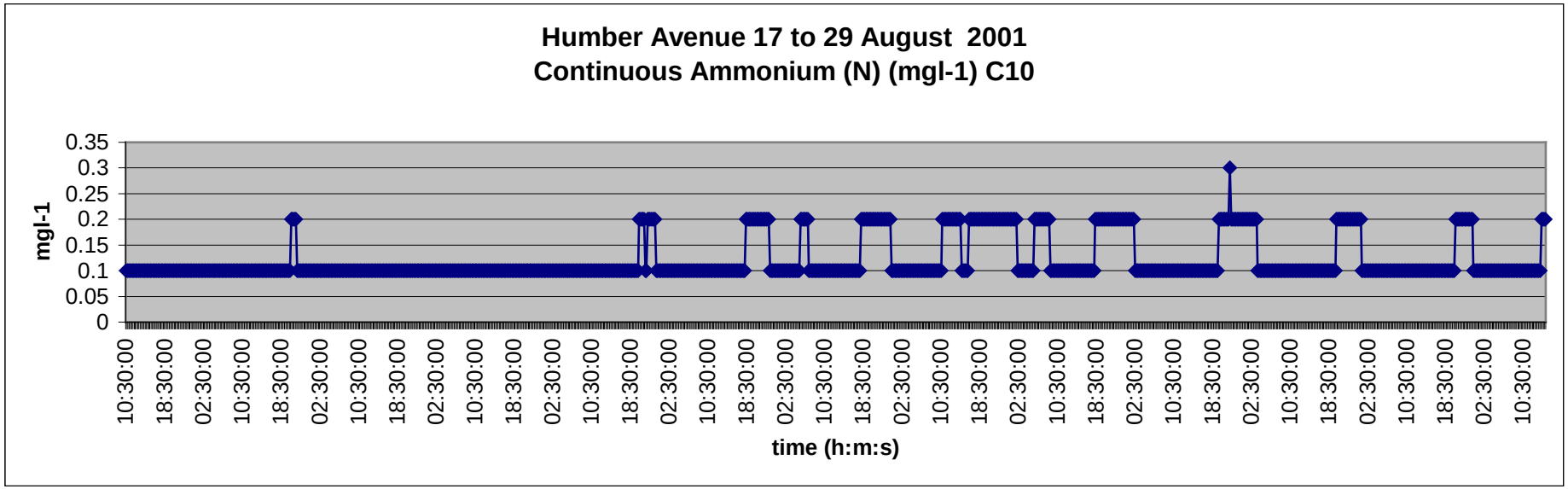

Meadow Street 27 July to 18 August 2001
Temperature (Degrees Centigrade) C9
deg C
20
15
10
5
0
13:45:00
02:45:00
15:45:00
04:45:00
17:45:00
06:45:00
19:45:00
08:45:00
21:45:00
10:45:00
23:45:00
12:45:00
01:45:00
14:45:00
03:45:00
16:45:00
05:45:00
18:45:00
07:45:00
20:45:00
09:45:00
22:45:00
11:45:00
00:45:00
13:45:00
02:45:00
15:45:00
04:45:00
17:45:00
06:45:00
19:45:00
08:45:00
21:45:00
10:45:00
23:45:00
12:45:00
01:45:00
14:45:00
03:45:00
time (h:m:s)

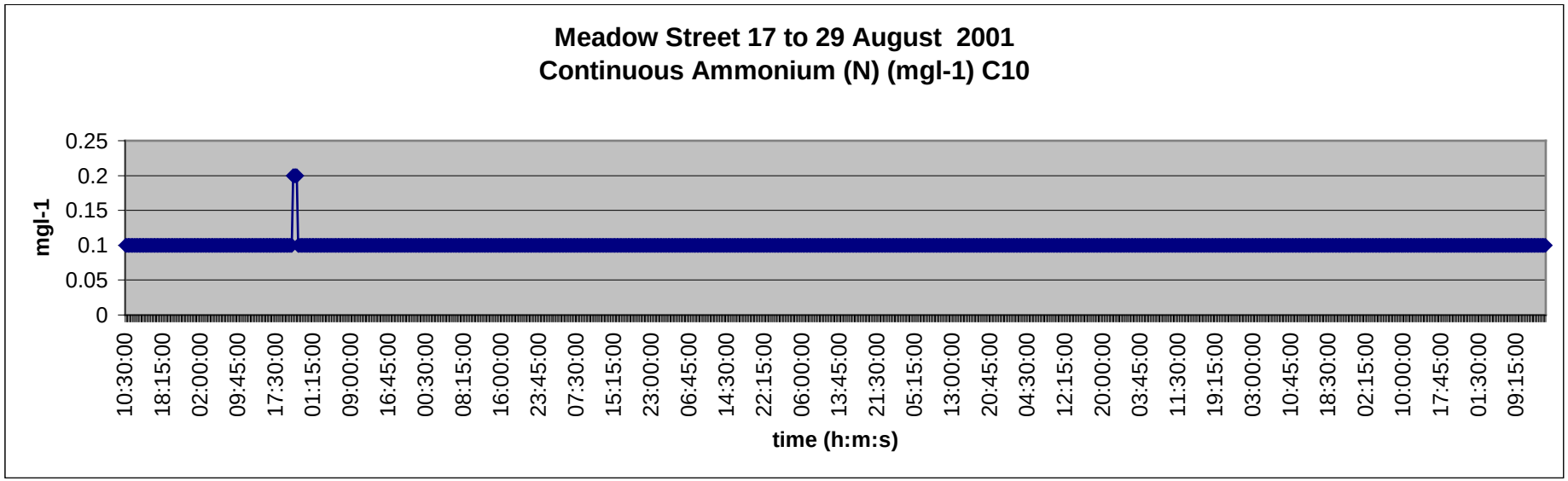
C10 Depth and Continuous monitors

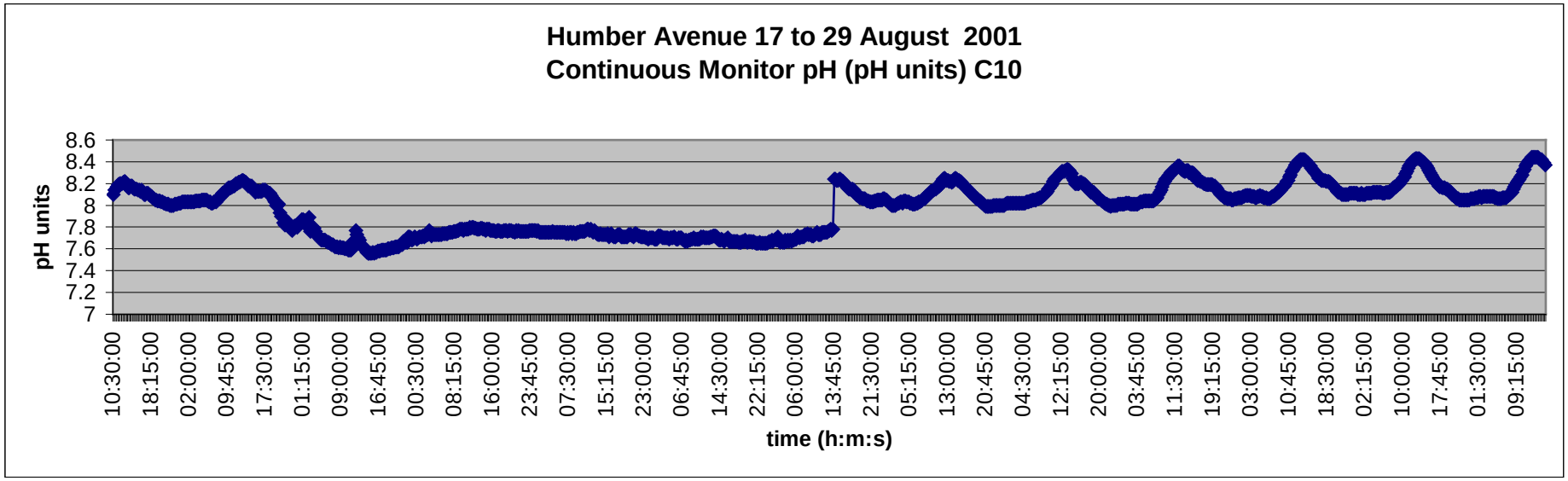


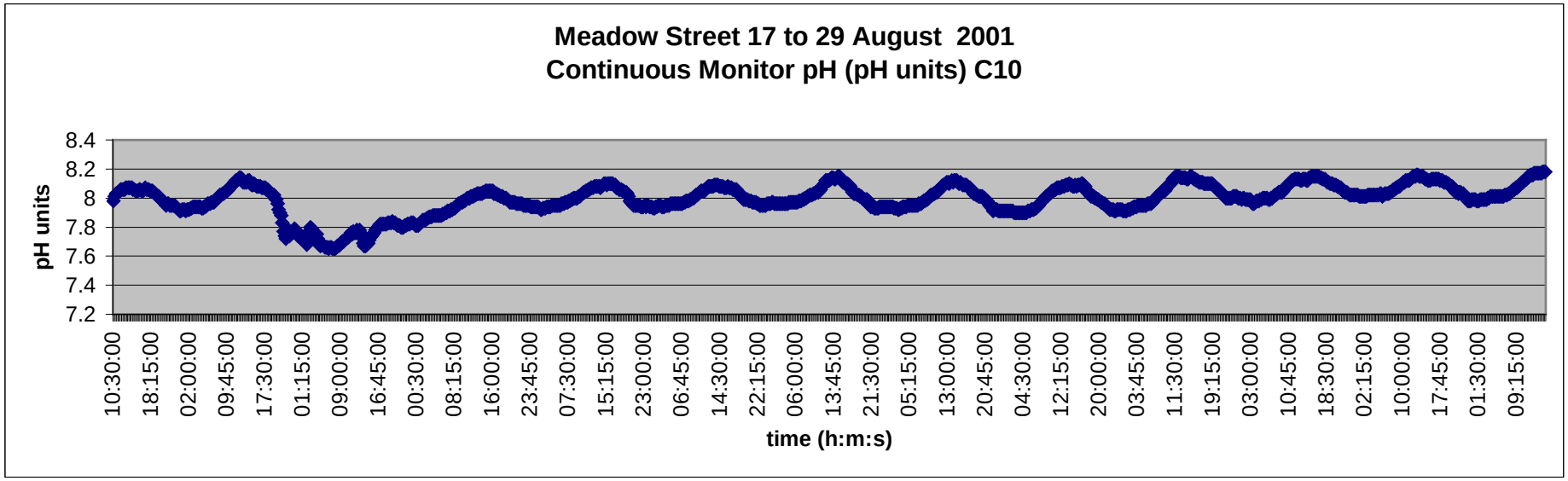

Humber Avenue 17 to 29 August 2001
Continuous DO (% saturation) C10
% saturation
120
100
80
60
40
20
0
10:30:00
18:15:00
02:00:00
09:45:00
17:30:00
01:15:00
09:00:00
16:45:00
00:30:00
08:15:00
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
time (h:m:s)

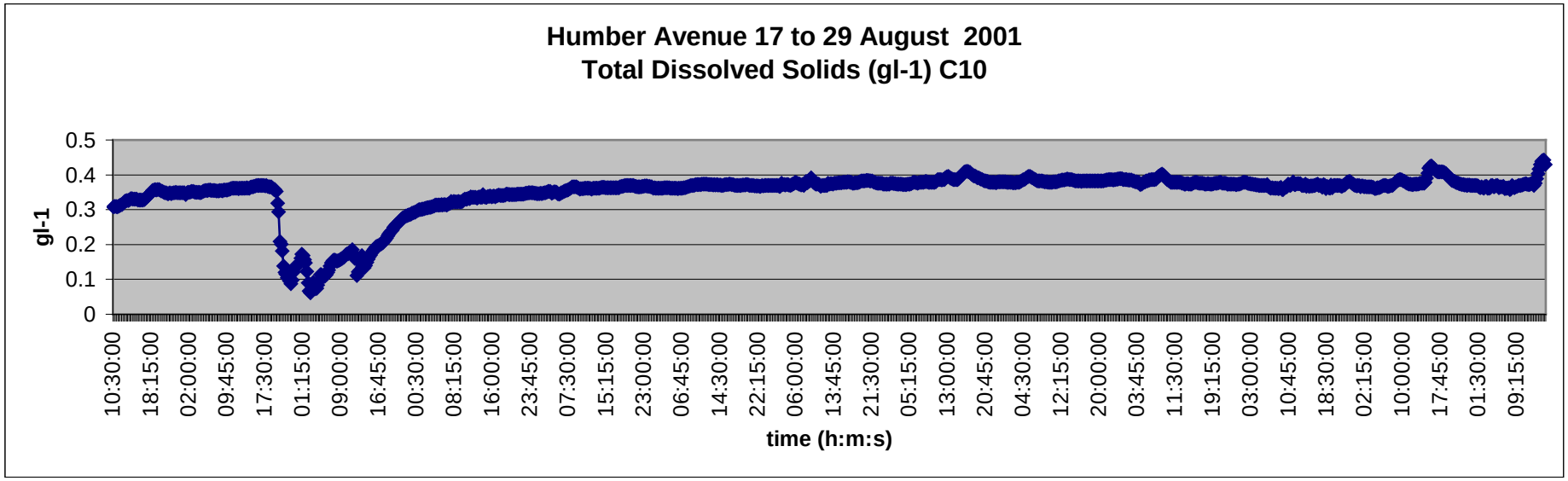

Meadow Street 17 to 29 August 2001
Continuous DO (% saturation) C10
% saturation
120
100
80
60
40
20
0
10:30:00
18:15:00
02:00:00
09:45:00
17:30:00
01:15:00
09:00:00
16:45:00
00:30:00
08:15:00
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
time (h:m:s)

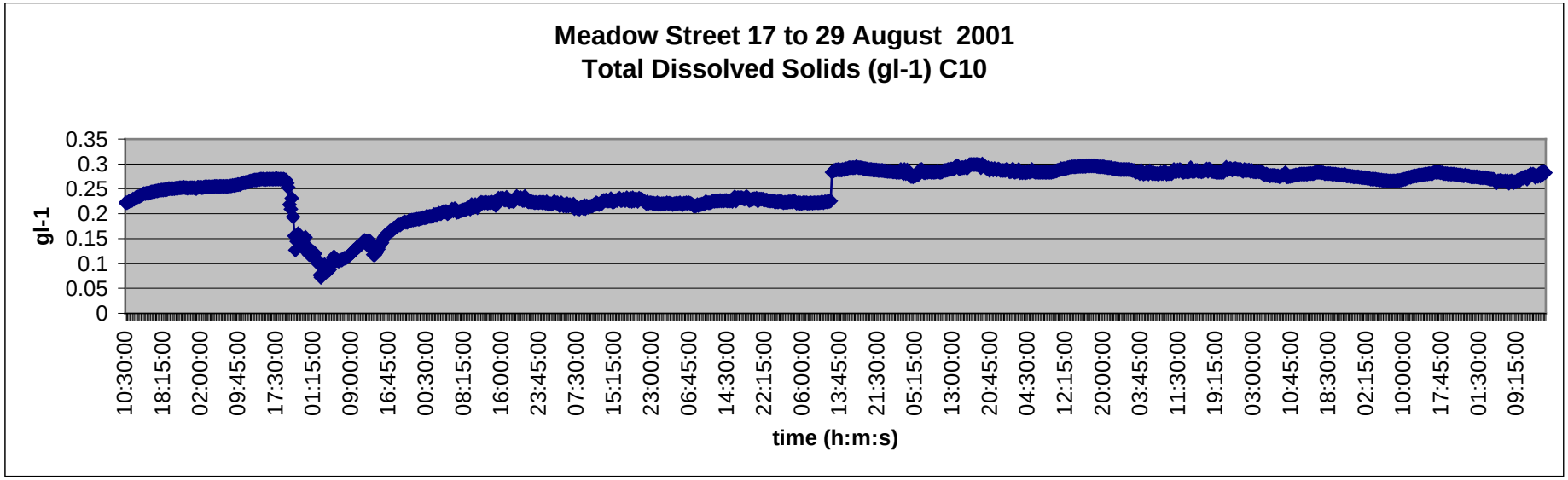

Humber Avenue 17 to 29 August 2001
Continuous Ammonium (N) (mgl-1) C10
mgl-1
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10:30:00
18:30:00
02:30:00
time (h:m:s)

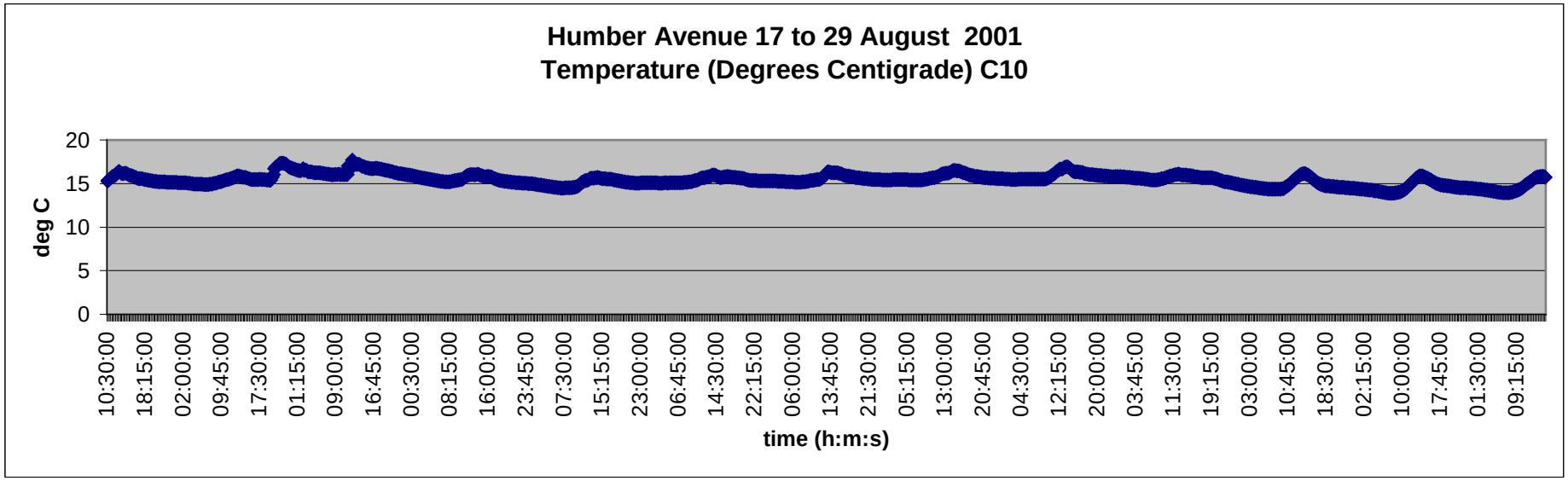

Meadow Street 17 to 29 August 2001
Continuous Ammonium (N) (mgl-1) C10
mgl-1
0.25
0.2
0.15
0.1
0.05
0
10:30:00
18:15:00
02:00:00
09:45:00
17:30:00
01:15:00
09:00:00
16:45:00
00:30:00
08:15:00
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
time (h:m:s)

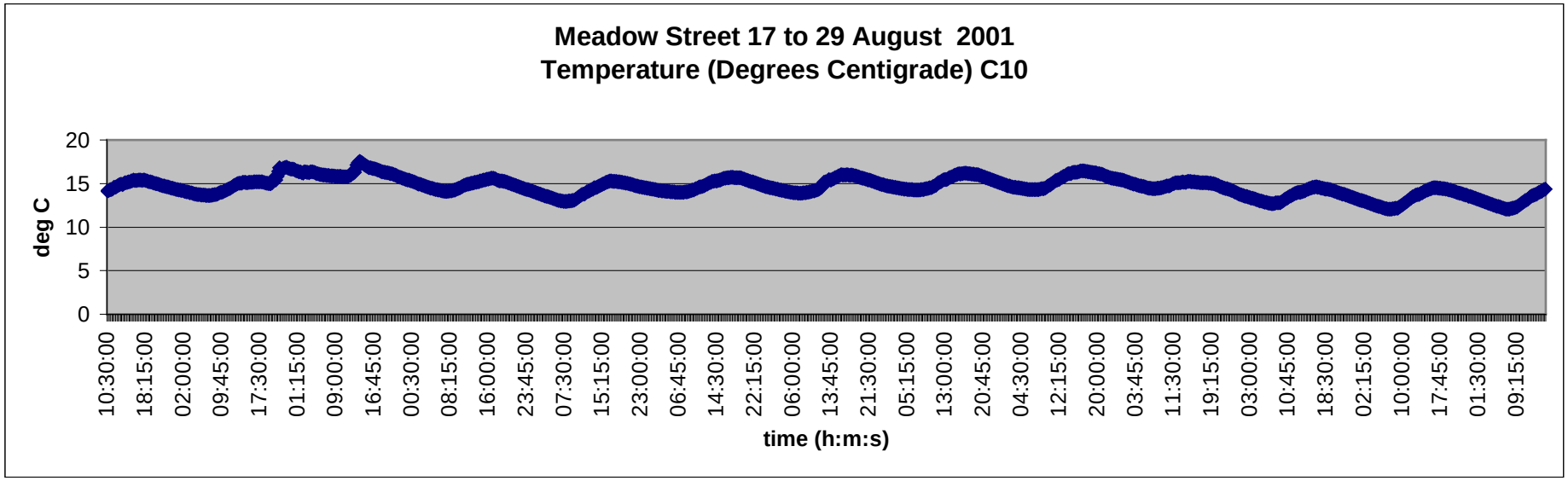

Humber Avenue 17 to 29 August 2001
Continuous Monitor pH (pH units) C10
pH units
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
10:30:00
18:15:00
02:00:00
09:45:00
17:30:00
01:15:00
09:00:00
16:45:00
00:30:00
08:15:00
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
time (h:m:s)


Meadow Street 17 to 29 August 2001
Continuous Monitor pH (pH units) C10
pH units
8.4
8.2
8
7.8
7.6
7.4
7.2
10:30:00
18:15:00
02:00:00
09:45:00
17:30:00
01:15:00
09:00:00
16:45:00
00:30:00
08:15:00
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
time (h:m:s)

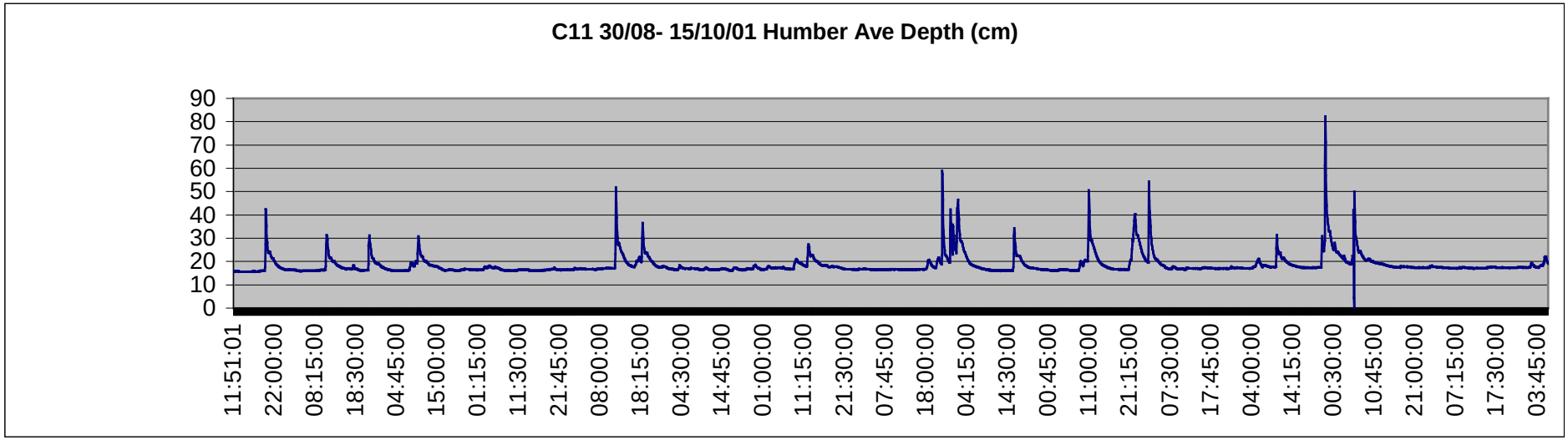

Humber Avenue 17 to 29 August 2001
Total Dissolved Solids (gl-1) C10
gl-1
0.5
0.4
0.3
0.2
0.1
0
10:30:00
18:15:00
02:00:00
09:45:00
17:30:00
01:15:00
09:00:00
16:45:00
00:30:00
08:15:00
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
time (h:m:s)


Meadow Street 17 to 29 August 2001
Total Dissolved Solids (gl-1) C10
gl-1
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10:30:00
18:15:00
02:00:00
09:45:00
17:30:00
01:15:00
09:00:00
16:45:00
00:30:00
08:15:00
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
time (h:m:s)

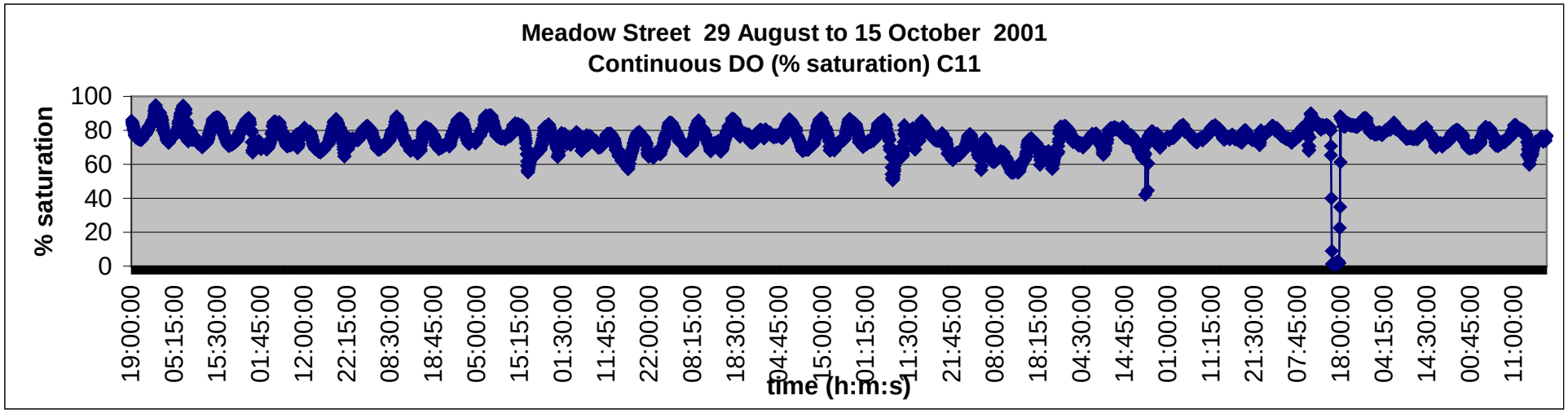

Humber Avenue 17 to 29 August 2001
Temperature (Degrees Centigrade) C10
deg C
20
15
10
5
0
10:30:00
18:15:00
02:00:00
09:45:00
17:30:00
01:15:00
09:00:00
16:45:00
00:30:00
08:15:00
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
time (h:m:s)


Meadow Street 17 to 29 August 2001
Temperature (Degrees Centigrade) C10
deg C
20
15
10
5
0
10:30:00
18:15:00
02:00:00
09:45:00
17:30:00
01:15:00
09:00:00
16:45:00
00:30:00
08:15:00
16:00:00
23:45:00
07:30:00
15:15:00
23:00:00
06:45:00
14:30:00
22:15:00
06:00:00
13:45:00
21:30:00
05:15:00
13:00:00
20:45:00
04:30:00
12:15:00
20:00:00
03:45:00
11:30:00
19:15:00
03:00:00
10:45:00
18:30:00
02:15:00
10:00:00
17:45:00
01:30:00
09:15:00
time (h:m:s)

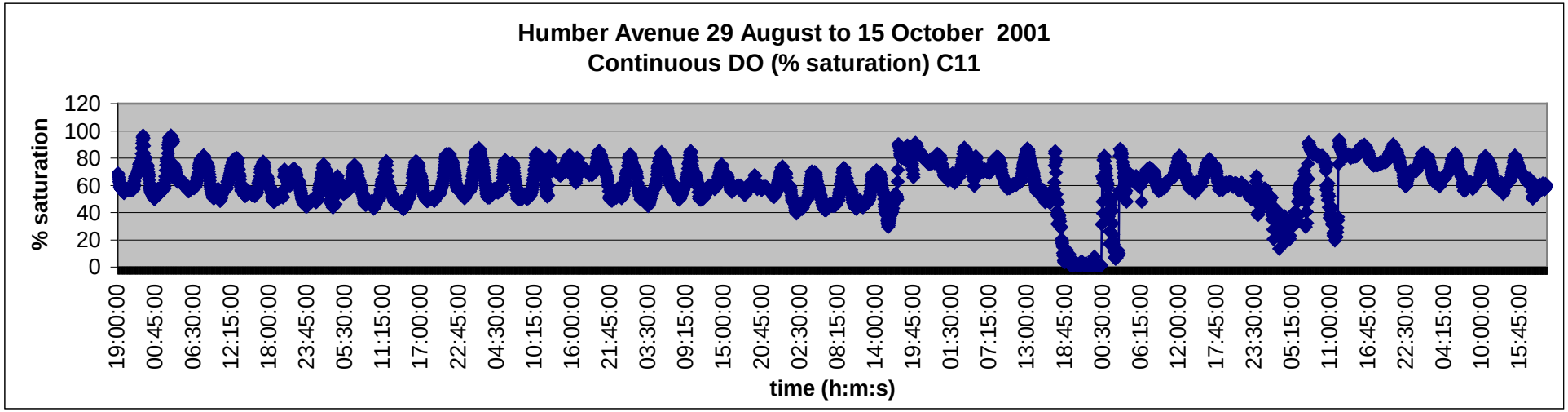
C11 Depth and Continuous Monitors
Depth



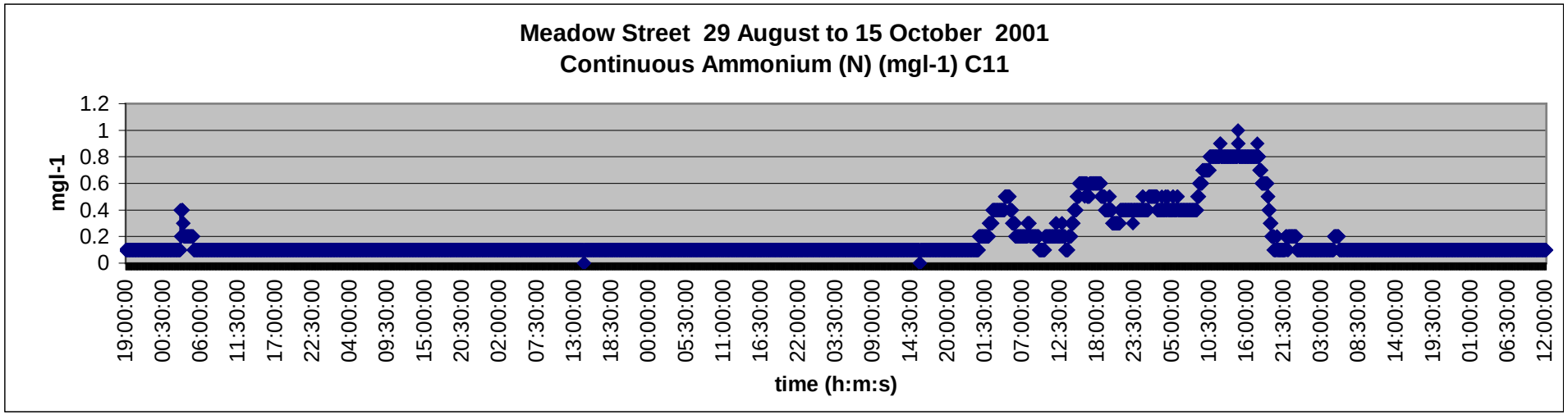
Meadow Street Continuous DO



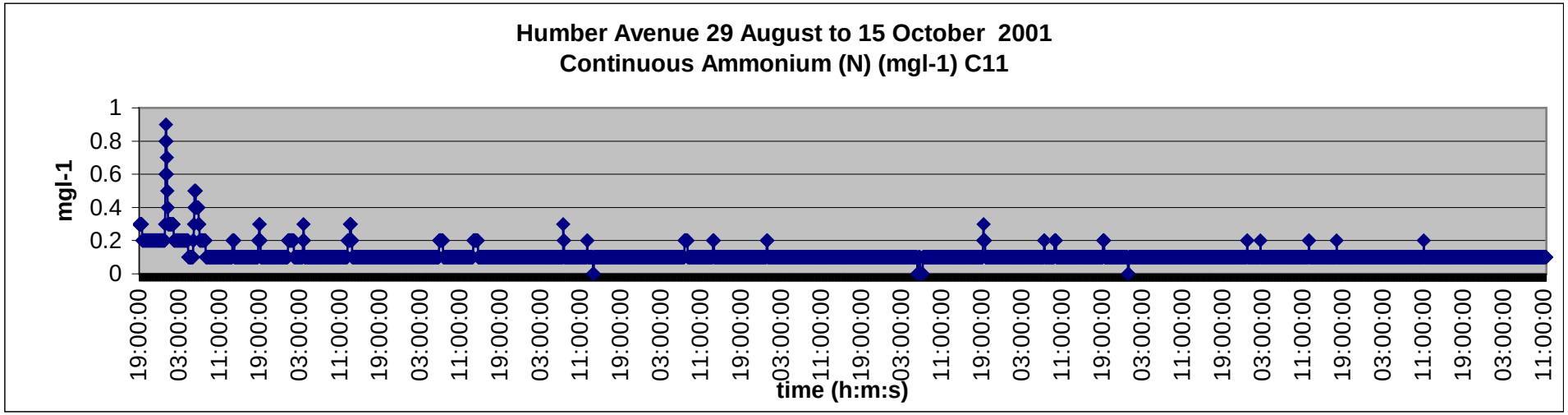
Humber Ave Continuous DO



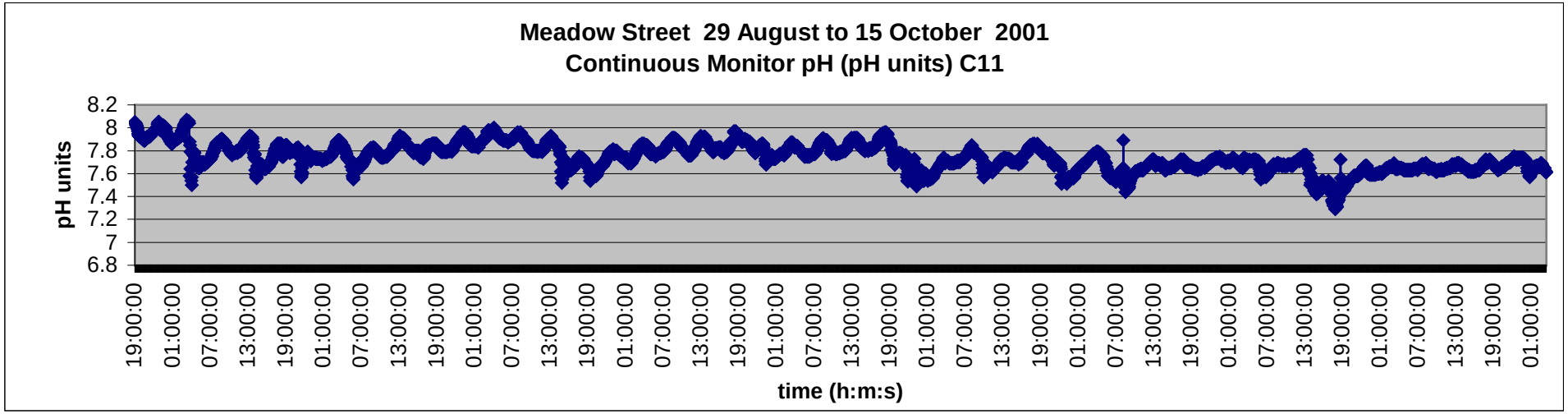
Meadow Street Continuous Ammonium



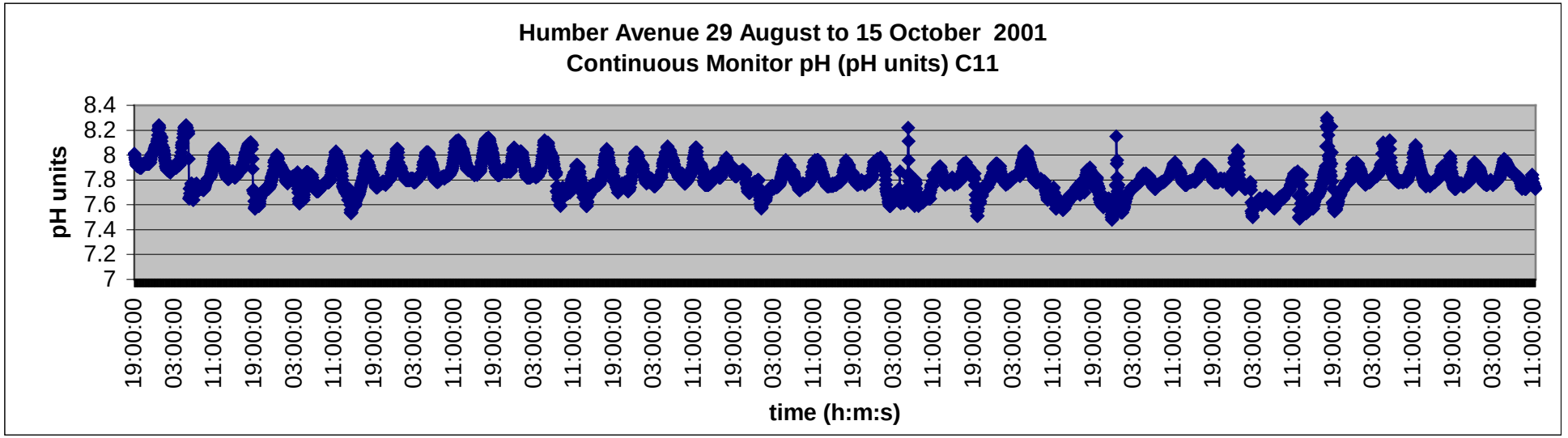
Humber Avenue Continuous Ammonium



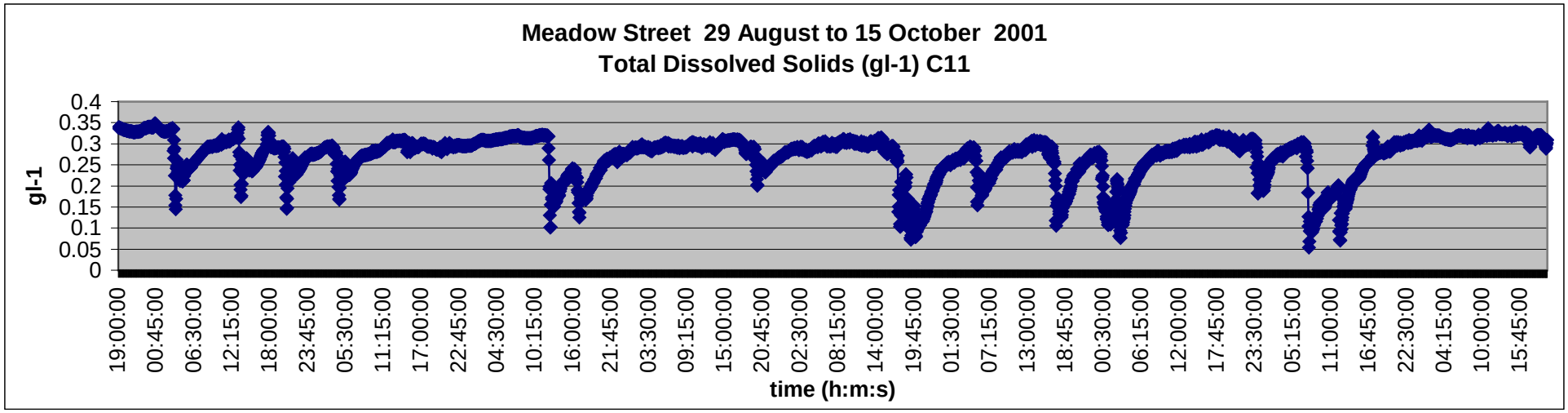
Meadow Street Continuous pH



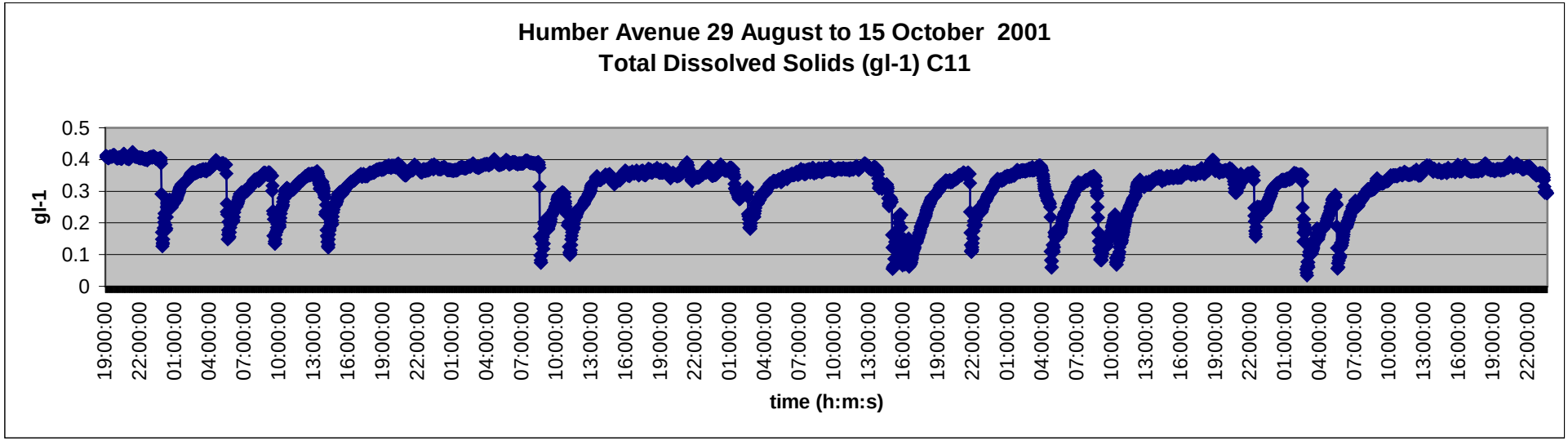
Humber Avenue Continuous pH



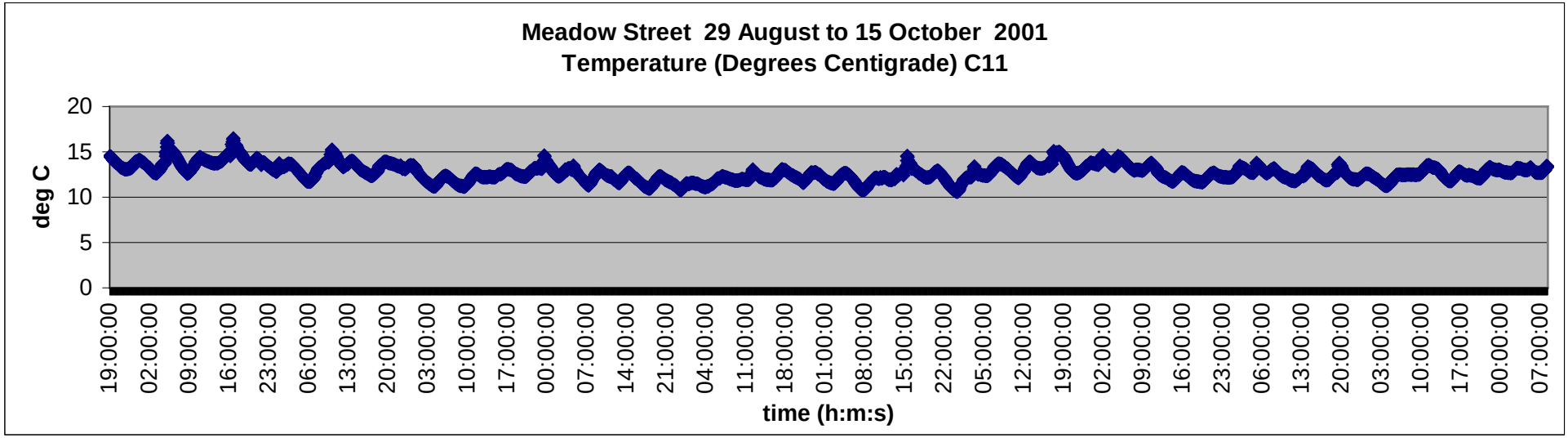
Meadow Street Continuous Total Dissolved Solids



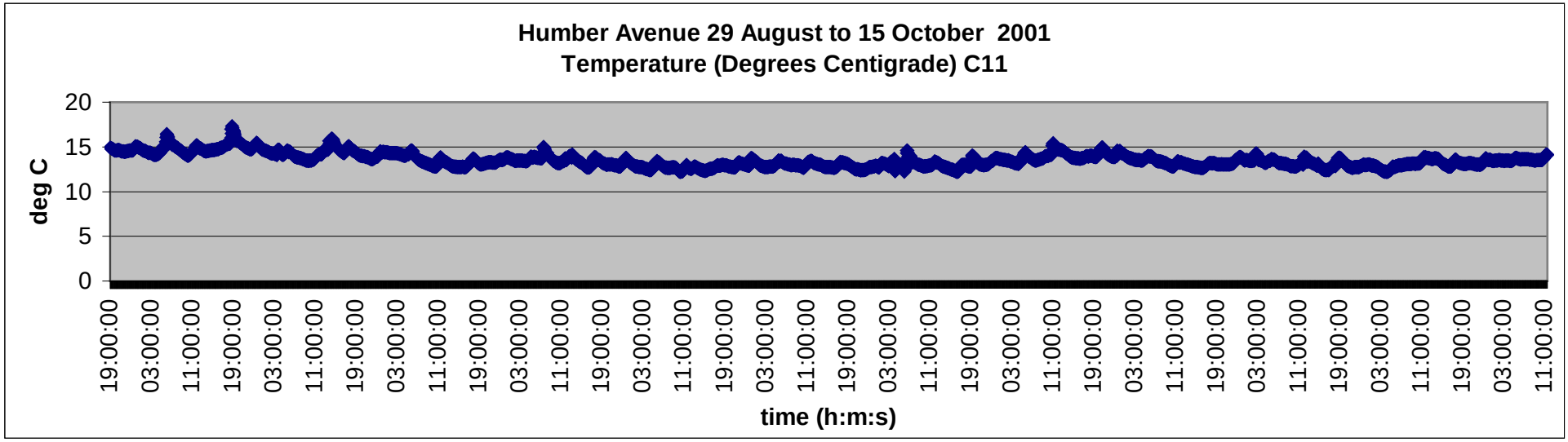
Humber Avenue Continuous Total Dissolved Solids



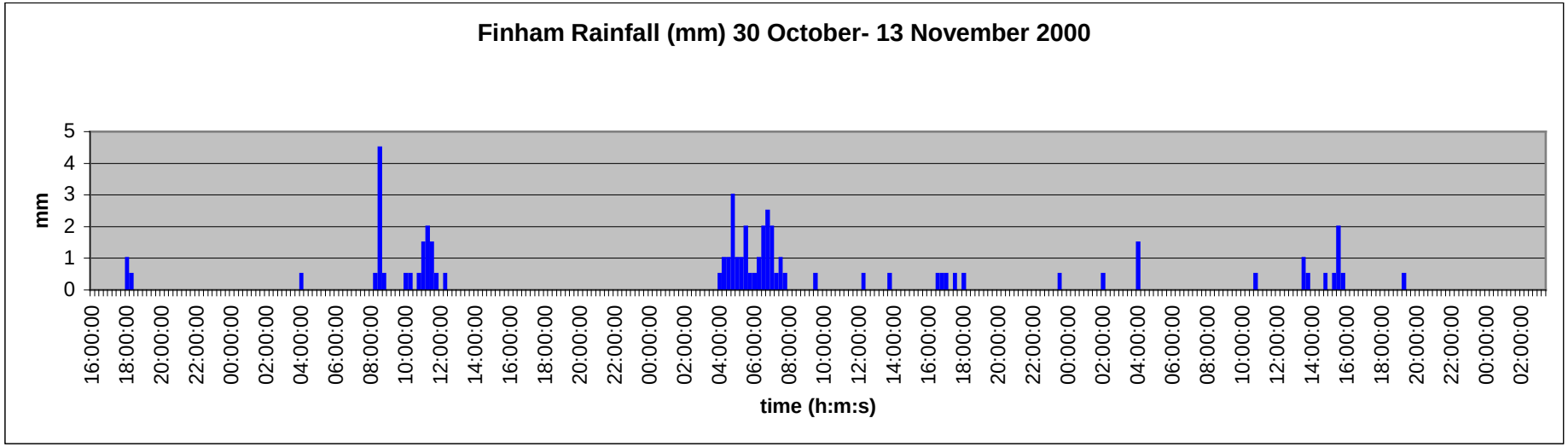
Meadow Street Continuous Temperature

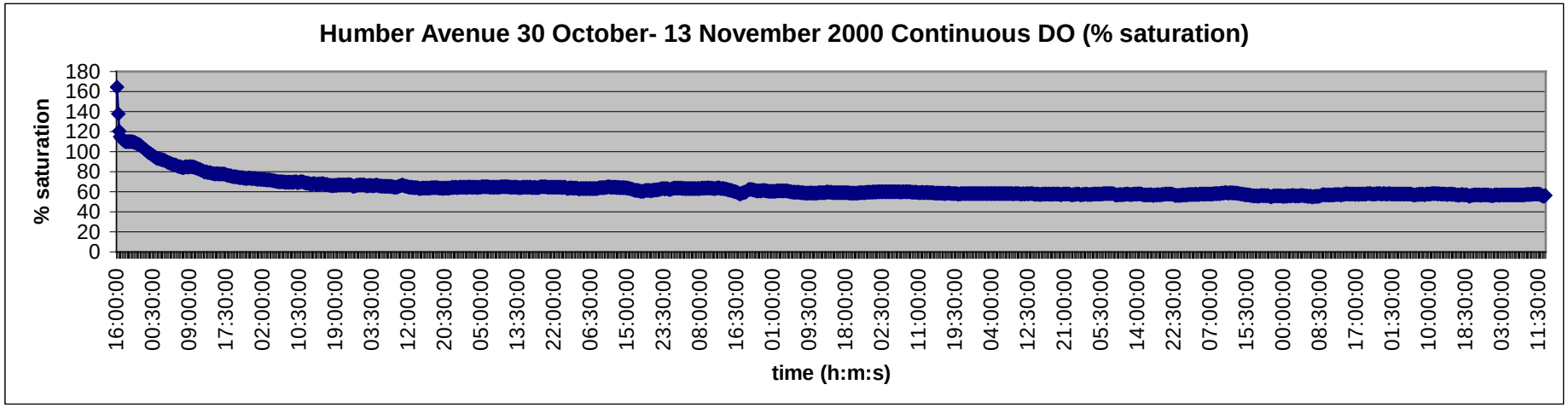


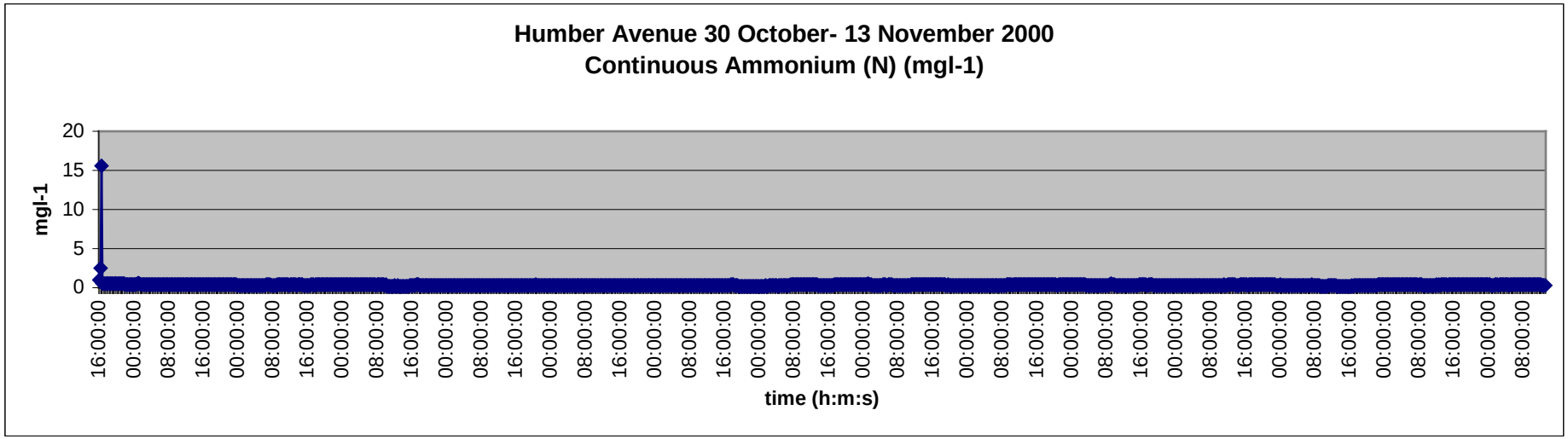
Humber Avenue Continuous Temperature

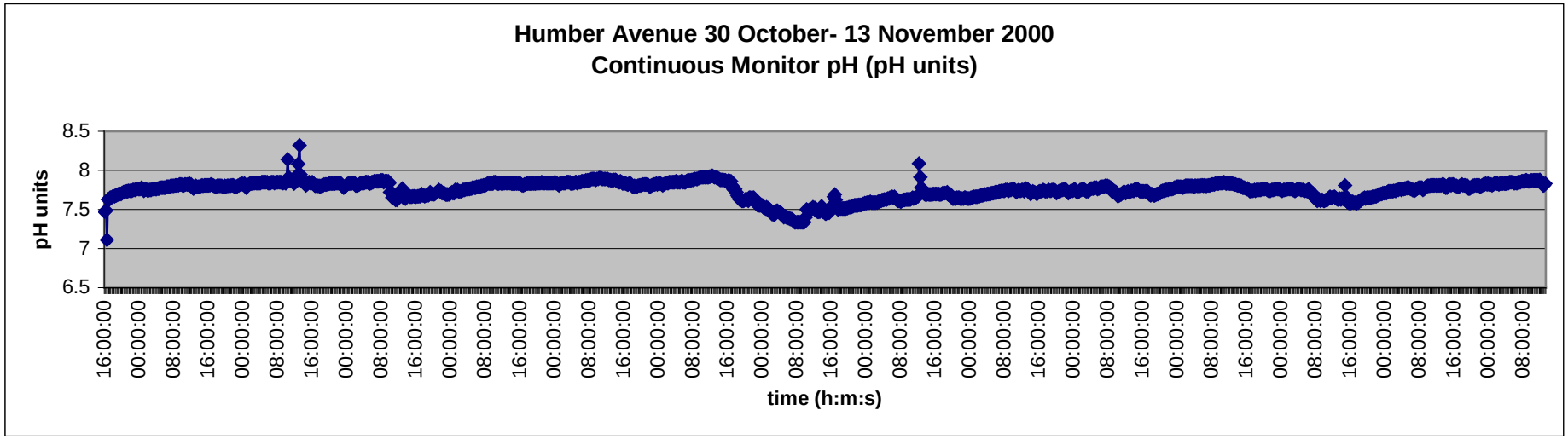


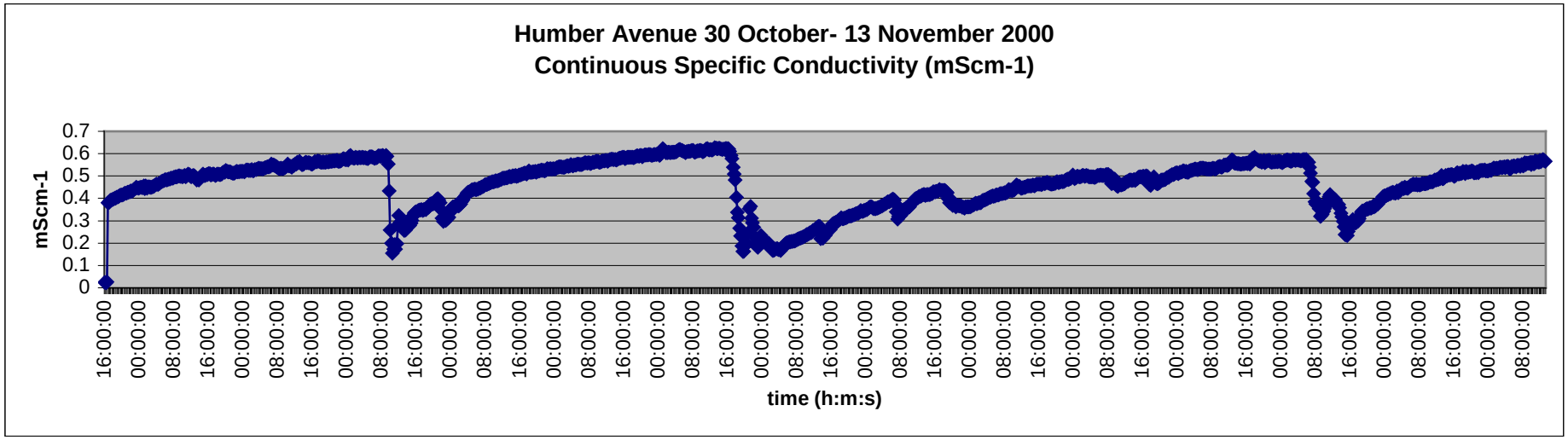
Continuous monitor run f) 30 October – 13 November 2000 (meadow Street monitor stolen)





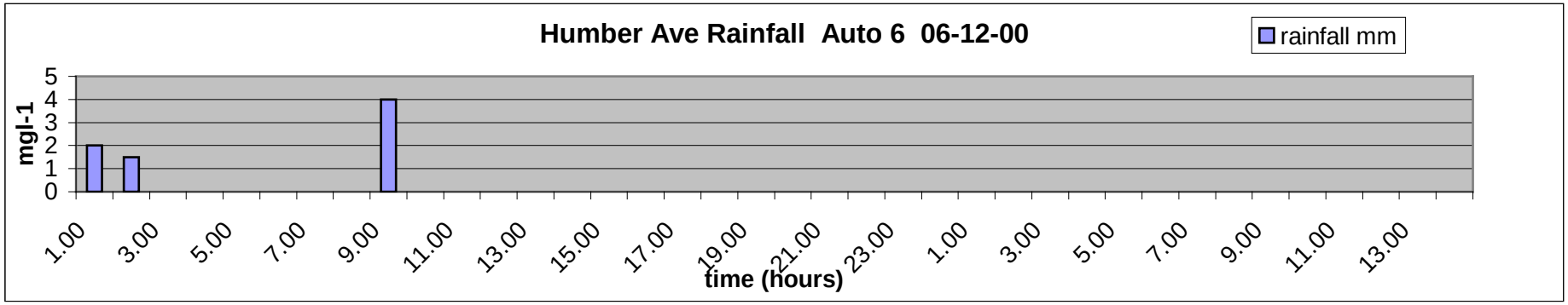

Humber Avenue 30 October- 13 November 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
20
15
10
5
0
16:00:00
00:00:00
08:00:00
time (h:m:s)

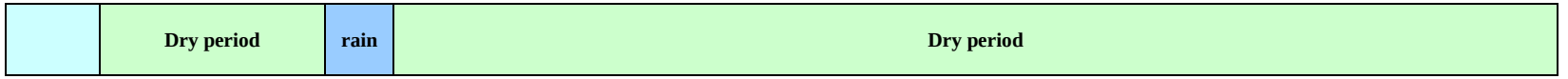

Humber Avenue 30 October- 13 November 2000
Continuous Monitor pH (pH units)
pH units
8.5
8
7.5
7
6.5
16:00:00
00:00:00
08:00:00
time (h:m:s)


Humber Avenue 30 October- 13 November 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
16:00:00
00:00:00
08:00:00
time (h:m:s)

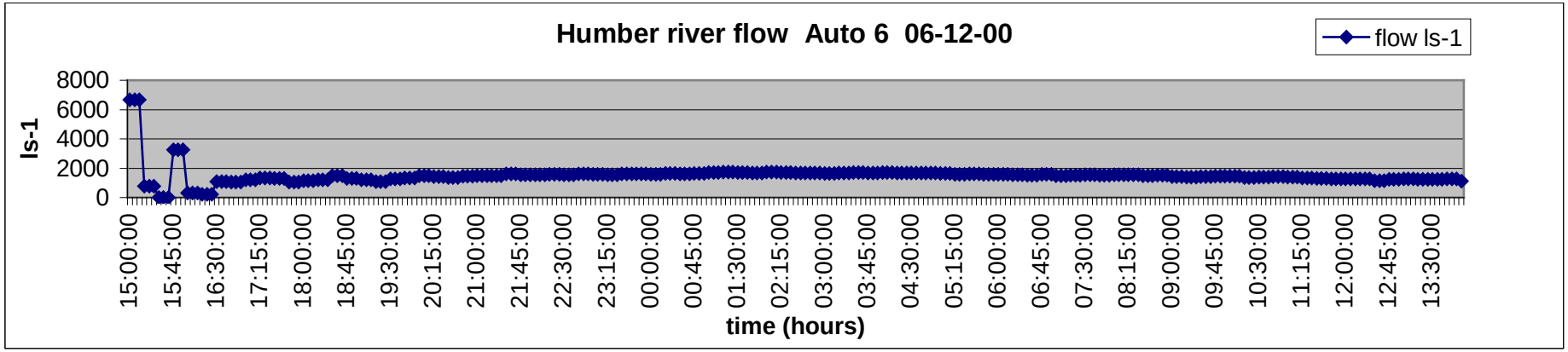
Auto 6 Humber Avenue 6-7 December 2000

a) Rainfall

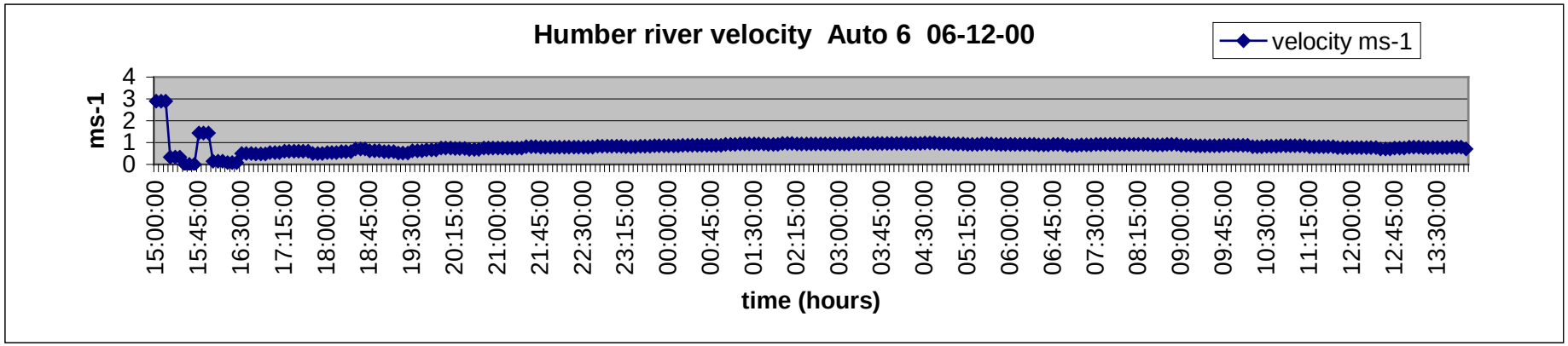


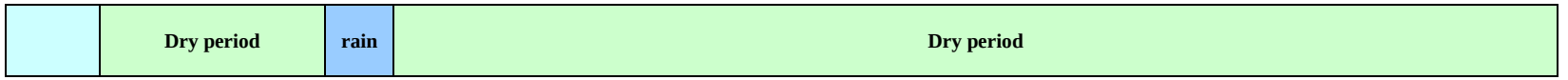


ai) River Flow

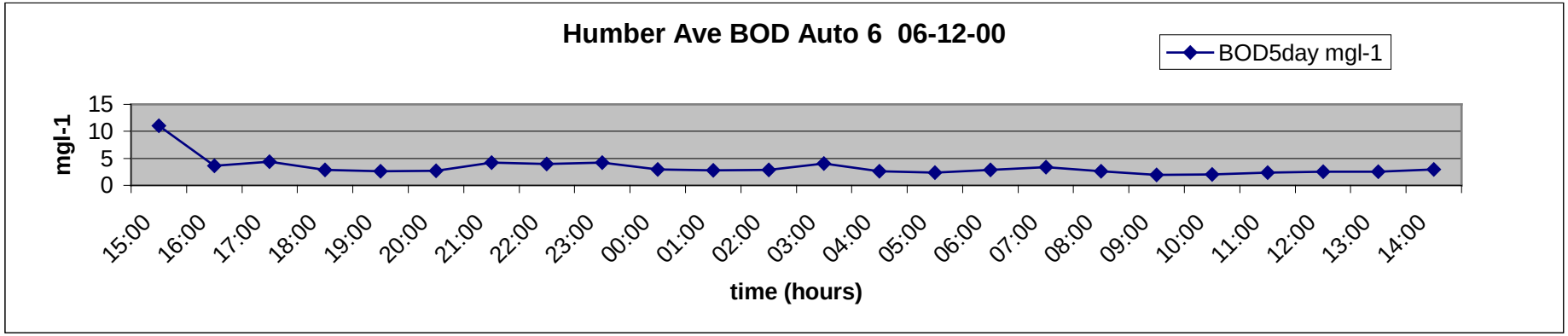


aii) River Velocity

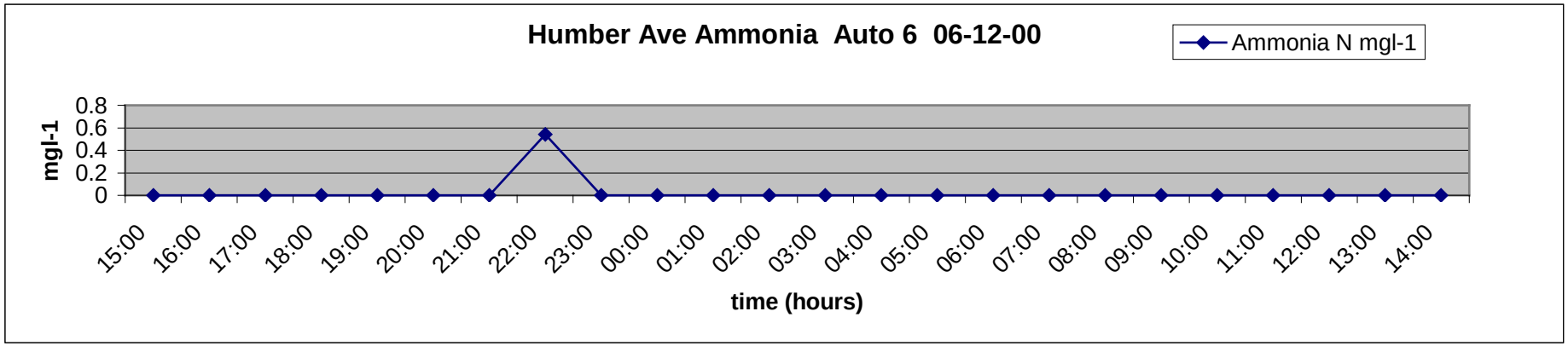


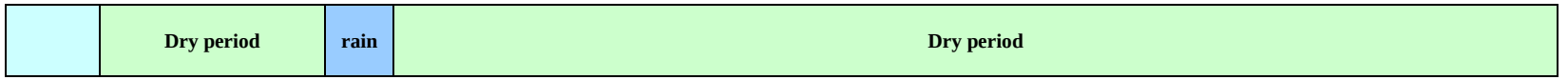


b) Biochemical Oxygen Demand BOD

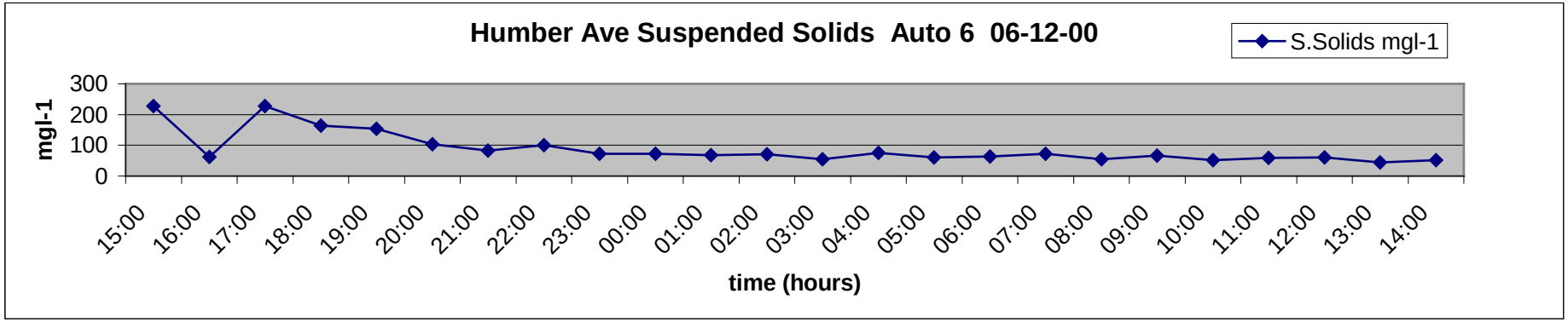


c) Ammonia

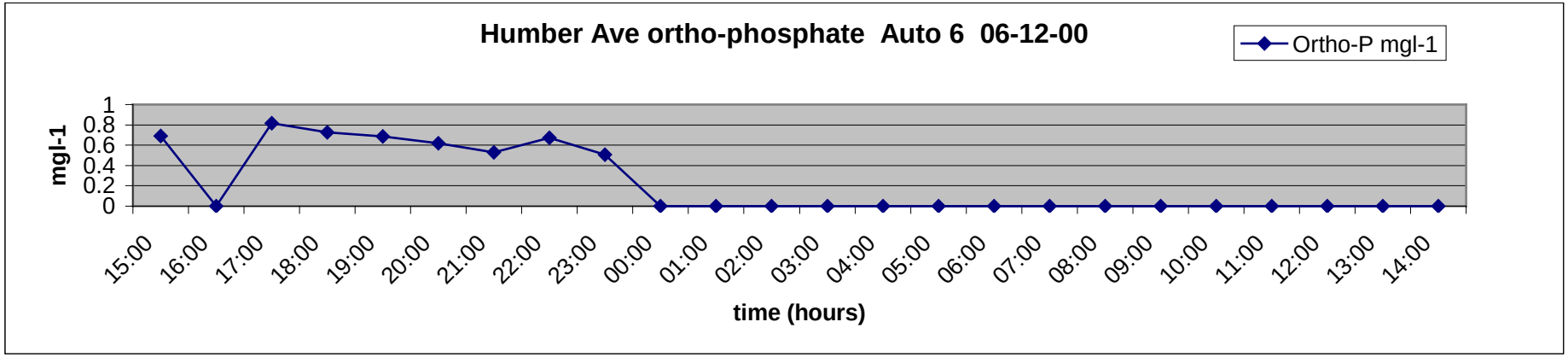


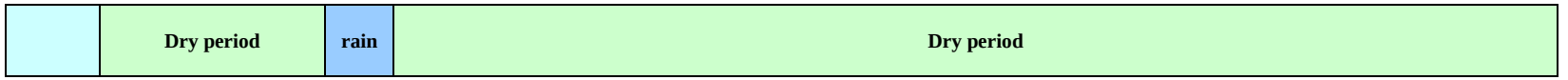


d) Suspended Solids

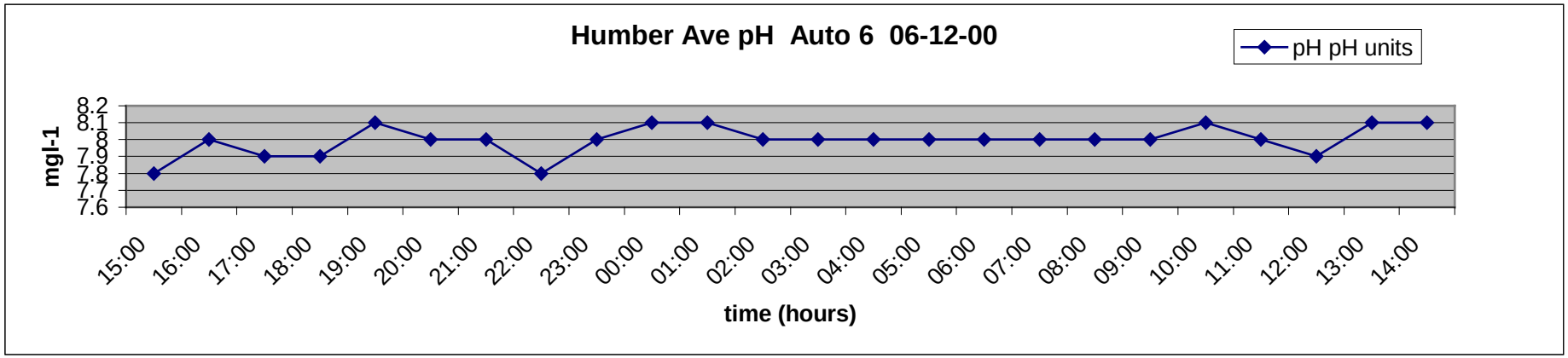


e) Ortho-phosphate

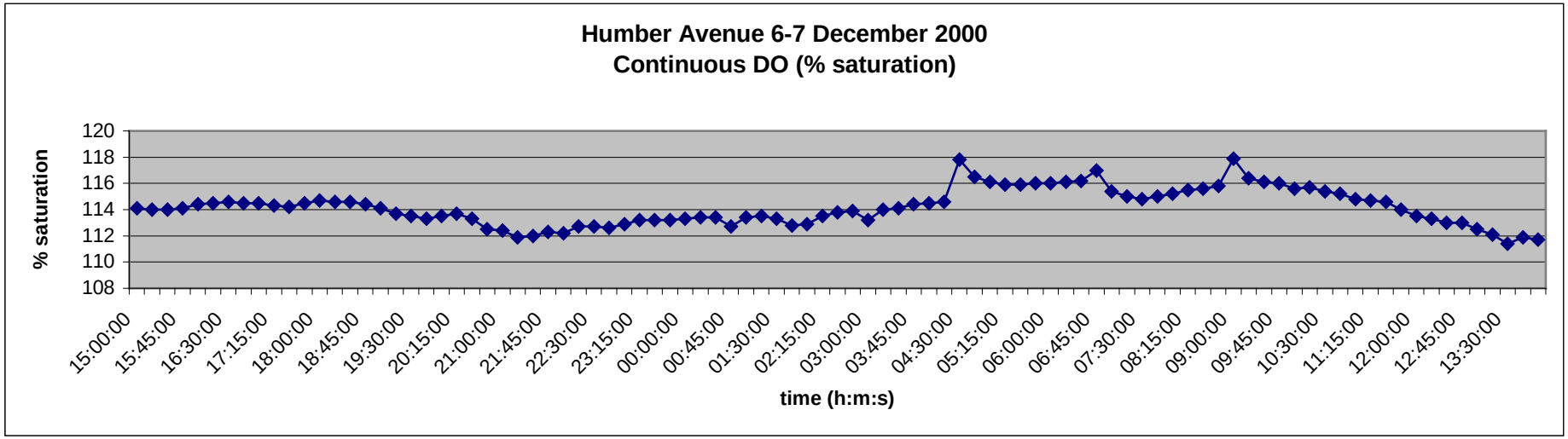


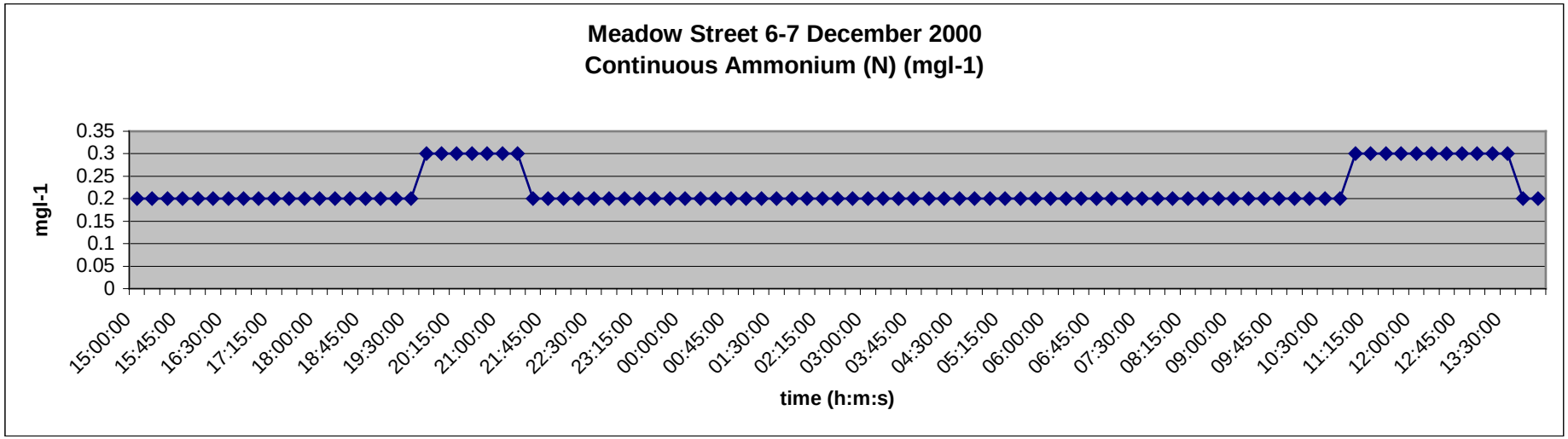


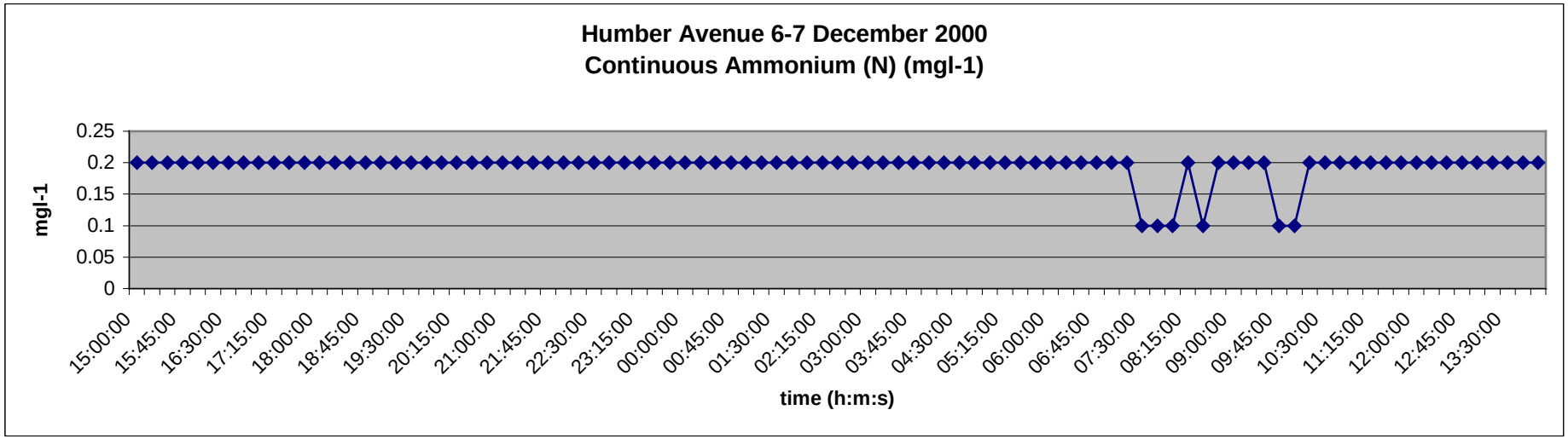
f) pH

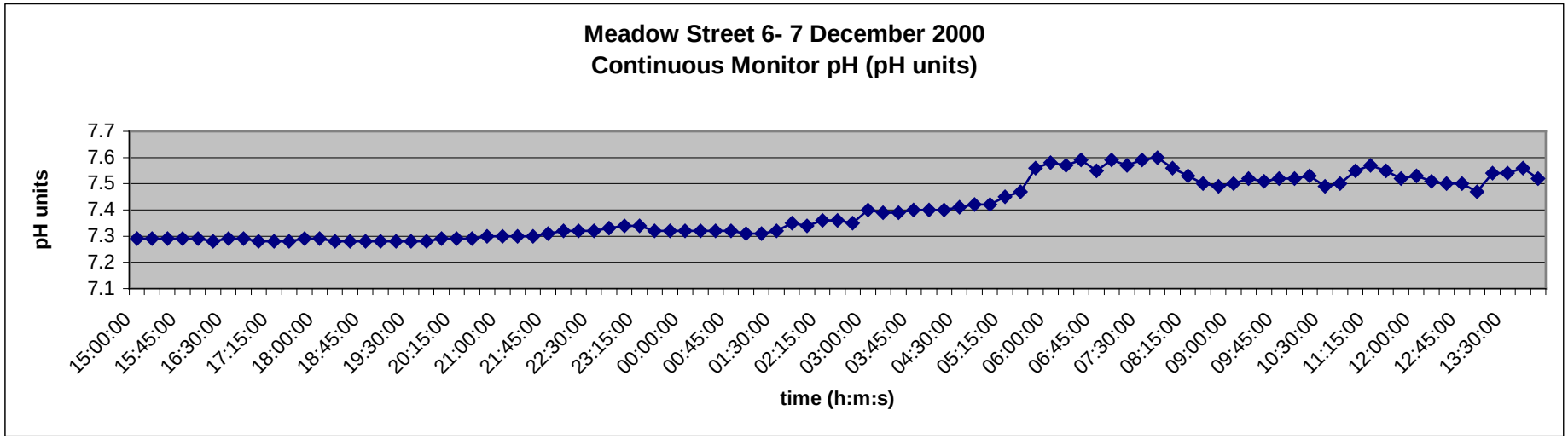


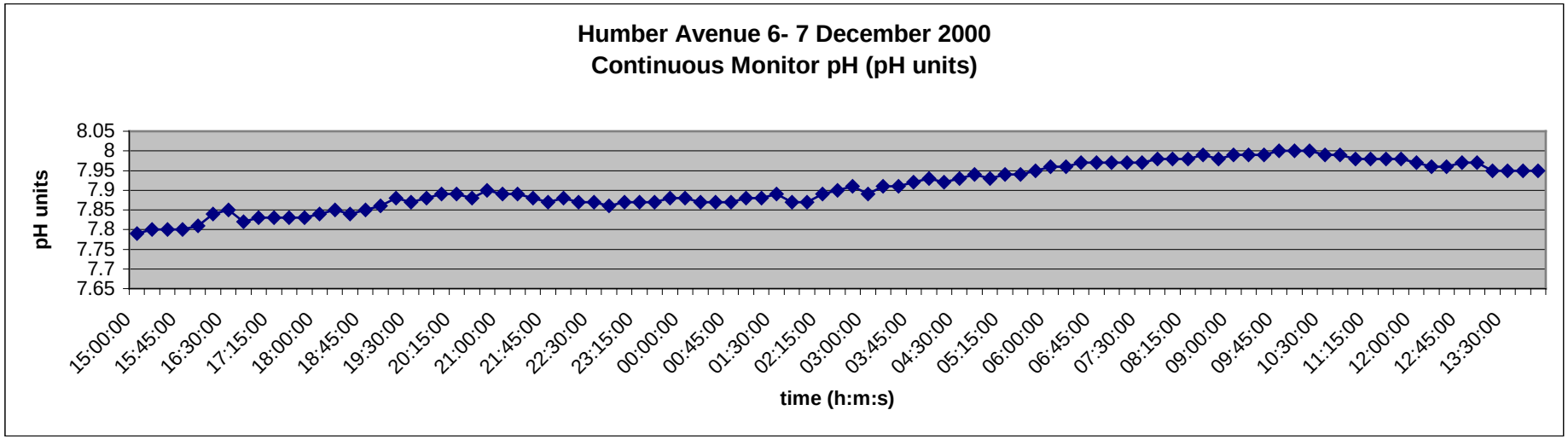
Auto6 Continuous monitors (dissolved oxygen probe at Meadow St malfunction) – dry weather

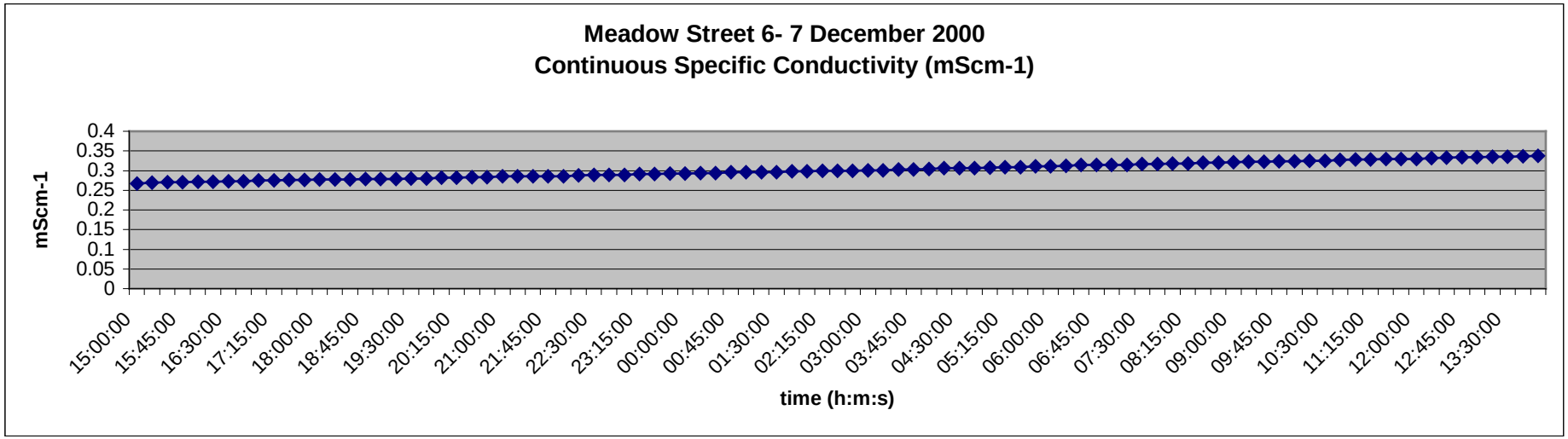


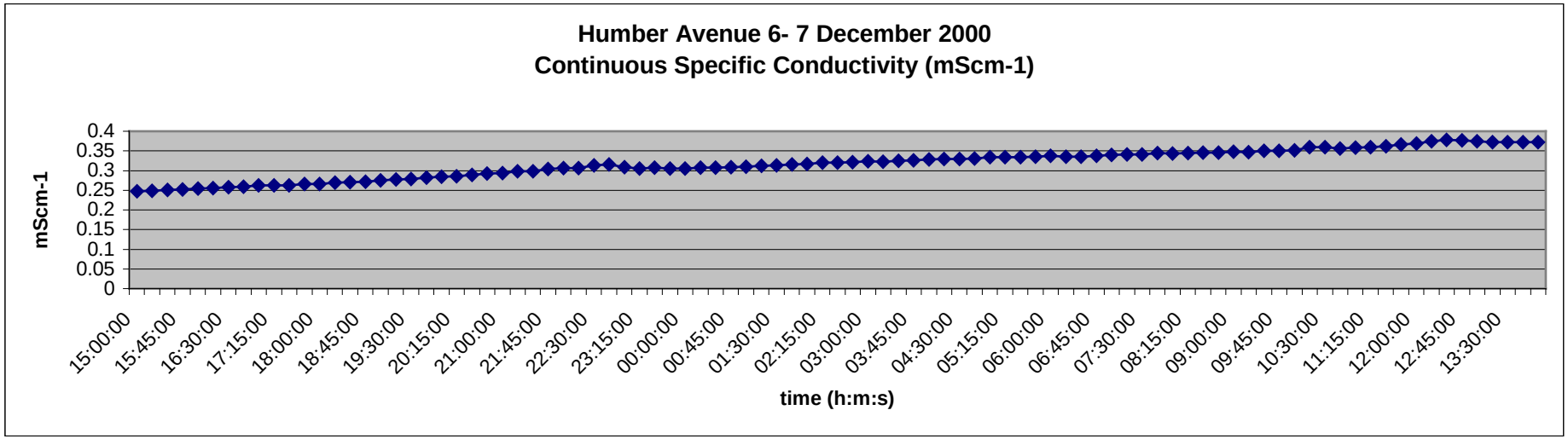

Meadow Street 6-7 December 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)


Humber Avenue 6-7 December 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
0.25
0.2
0.15
0.1
0.05
0
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)


Meadow Street 6- 7 December 2000
Continuous Monitor pH (pH units)
pH units
7.7
7.6
7.5
7.4
7.3
7.2
7.1
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

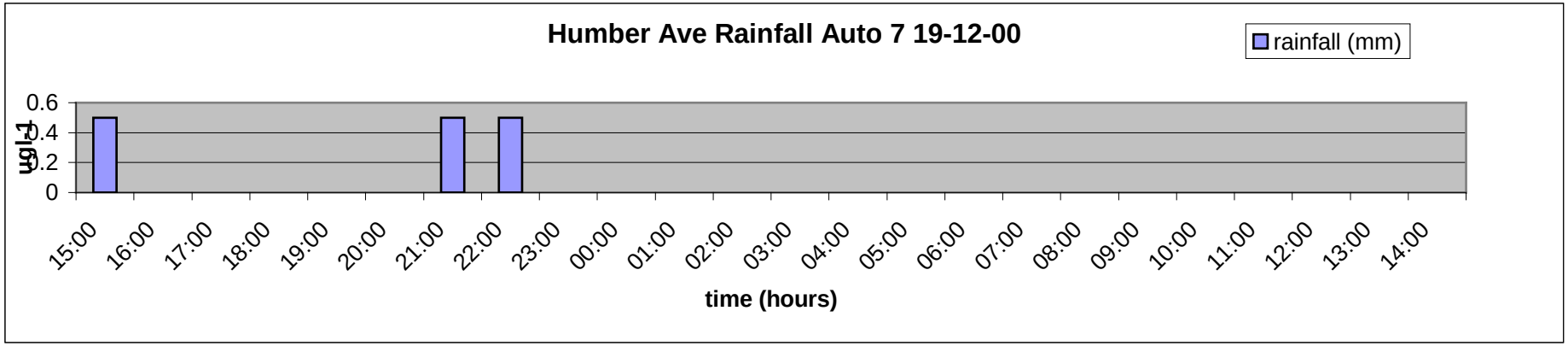

Humber Avenue 6- 7 December 2000
Continuous Monitor pH (pH units)
pH units
8.05
8
7.95
7.9
7.85
7.8
7.75
7.7
7.65
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

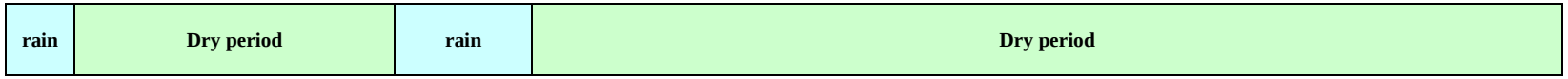

Meadow Street 6- 7 December 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)


Humber Avenue 6- 7 December 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

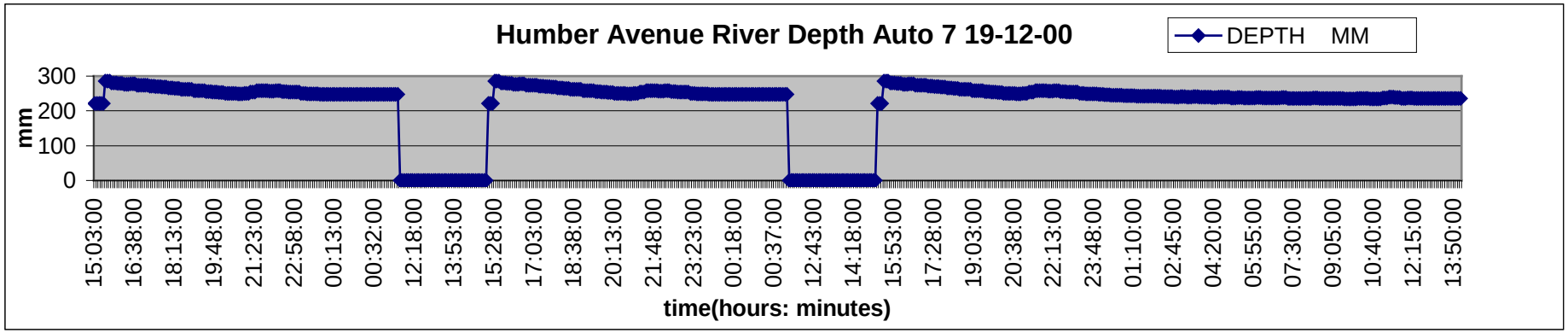
Auto 7 Humber Avenue 19-20 December 2000

a) Rainfall

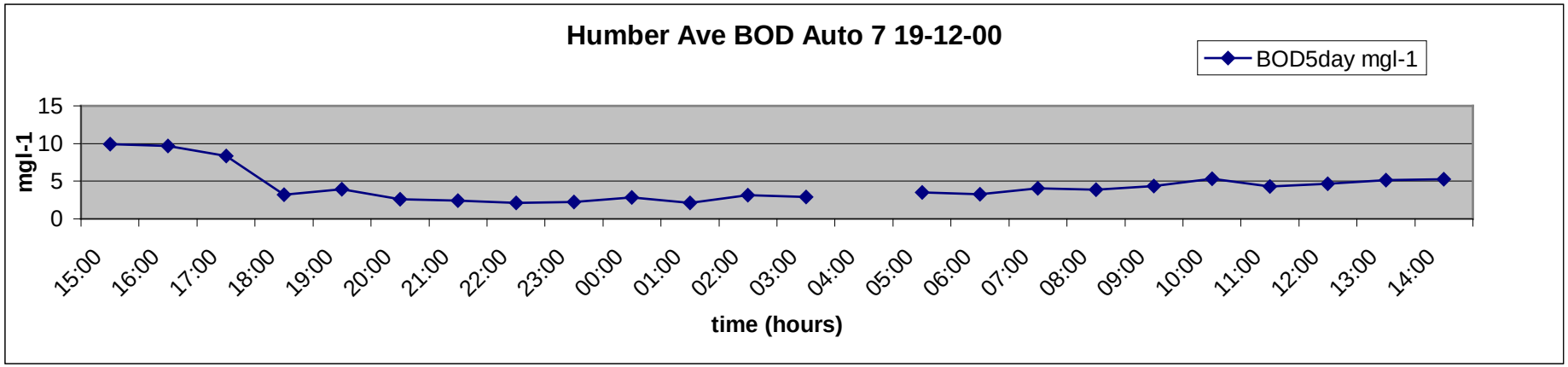


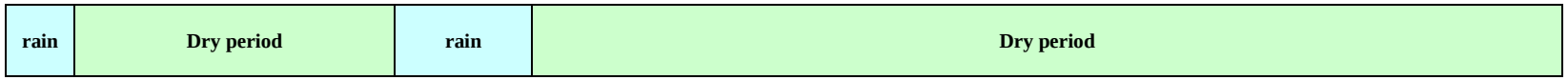


ai) River depth (Equipment affected by debris) flow and velocity not identified

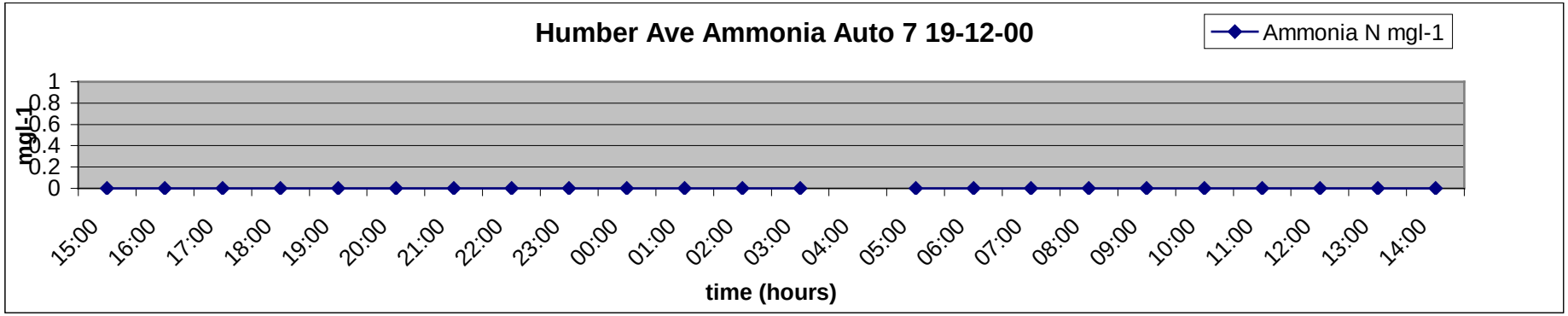


b) Biochemical Oxygen Demand (BOD)

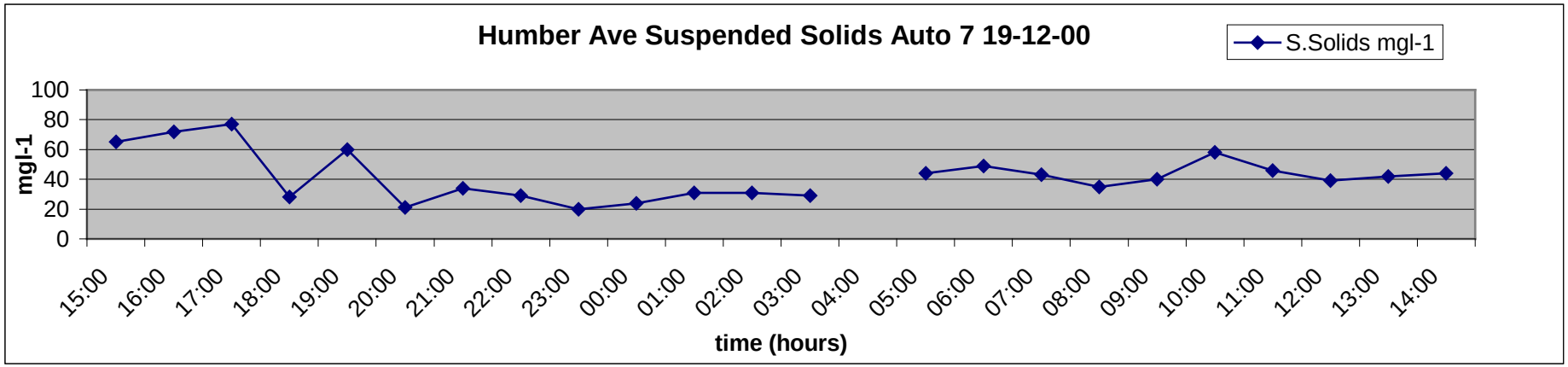


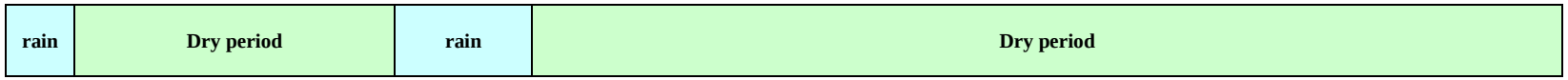


c) Ammonia

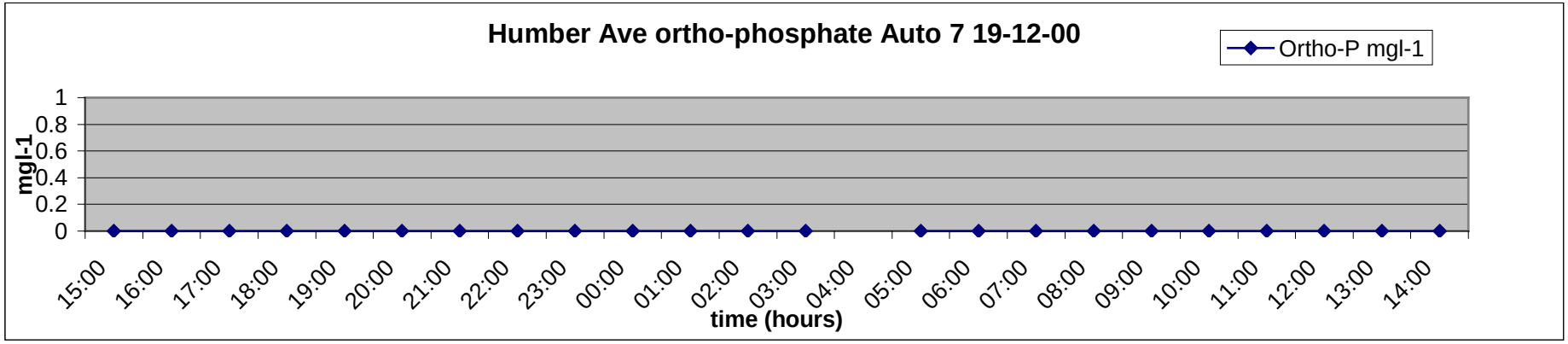


d) Suspended Solids

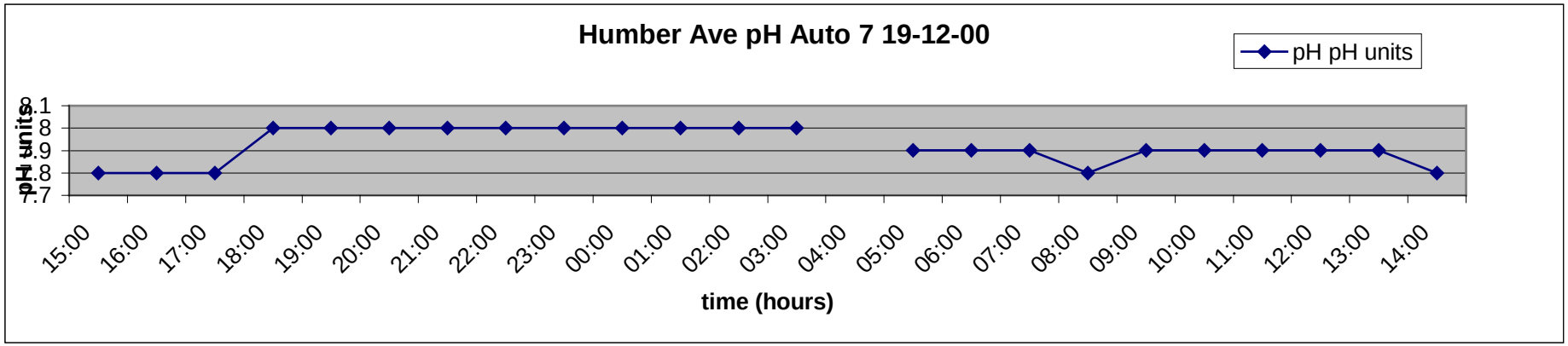


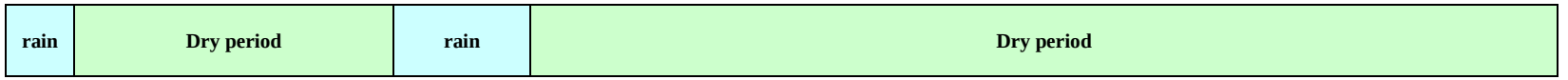


e) Ortho-phosphate

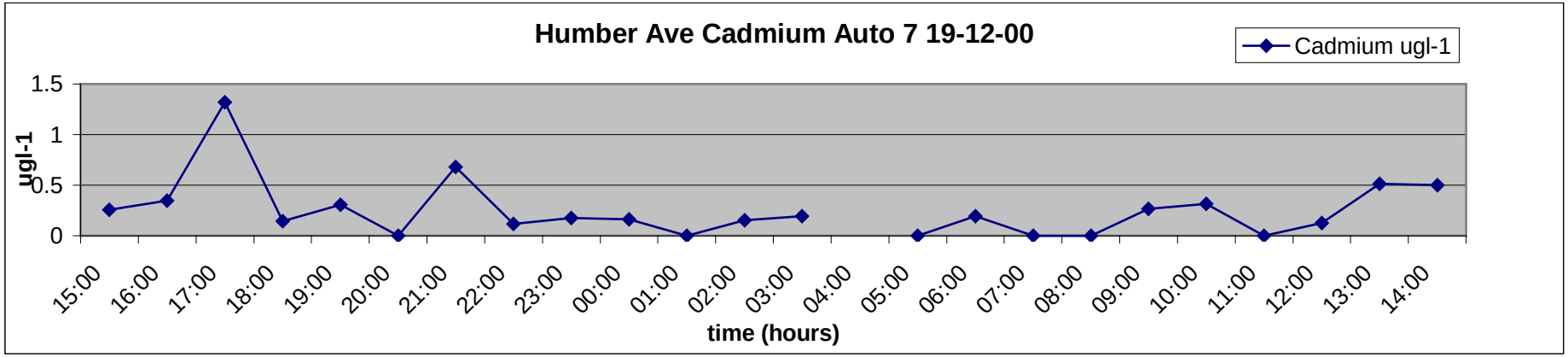


f) pH

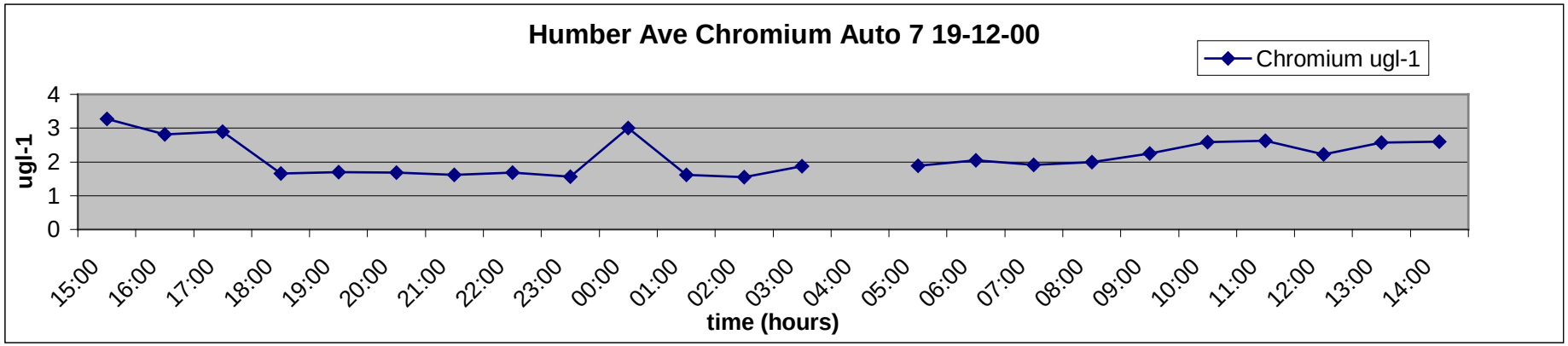


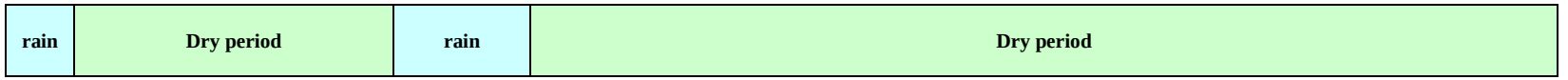


g) Cadmium

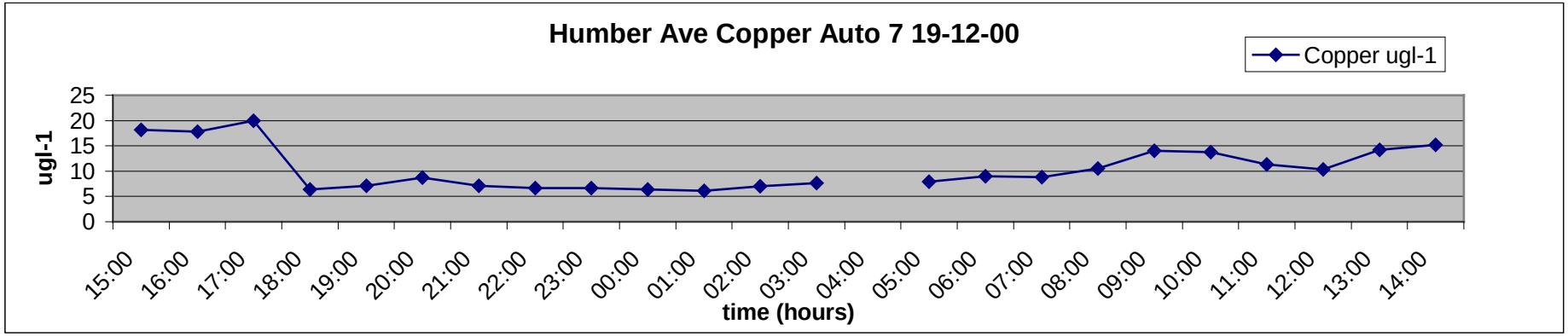


h) Chromium

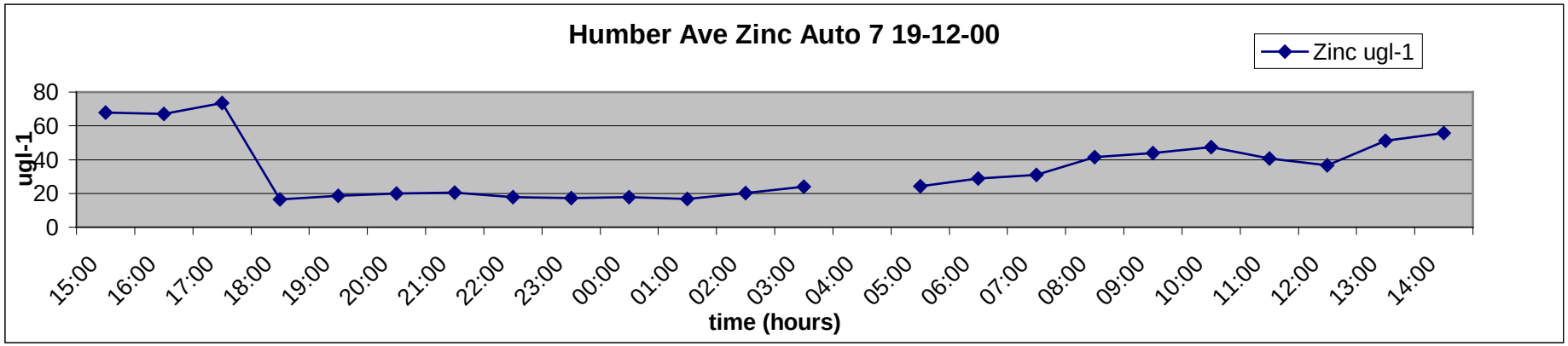




i) Copper

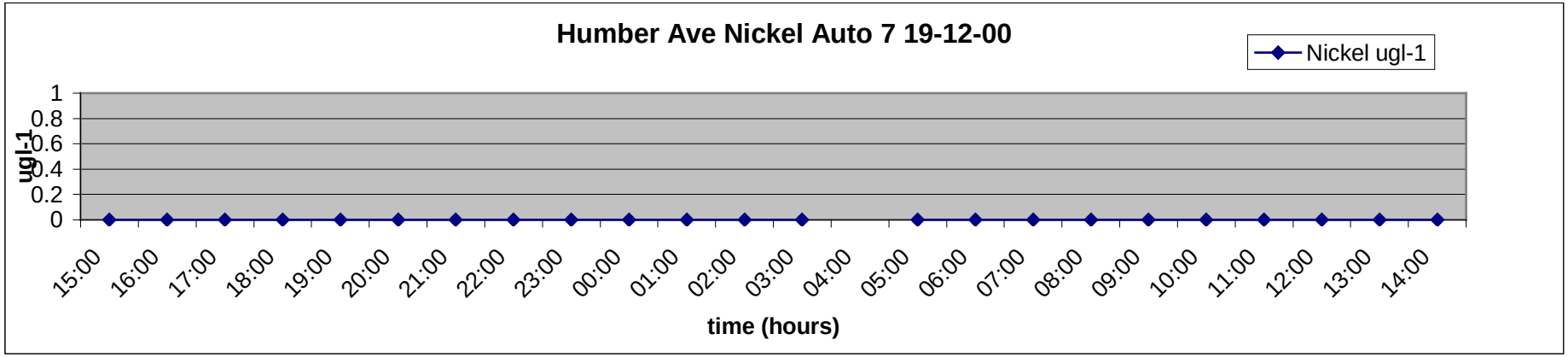


j) Zinc

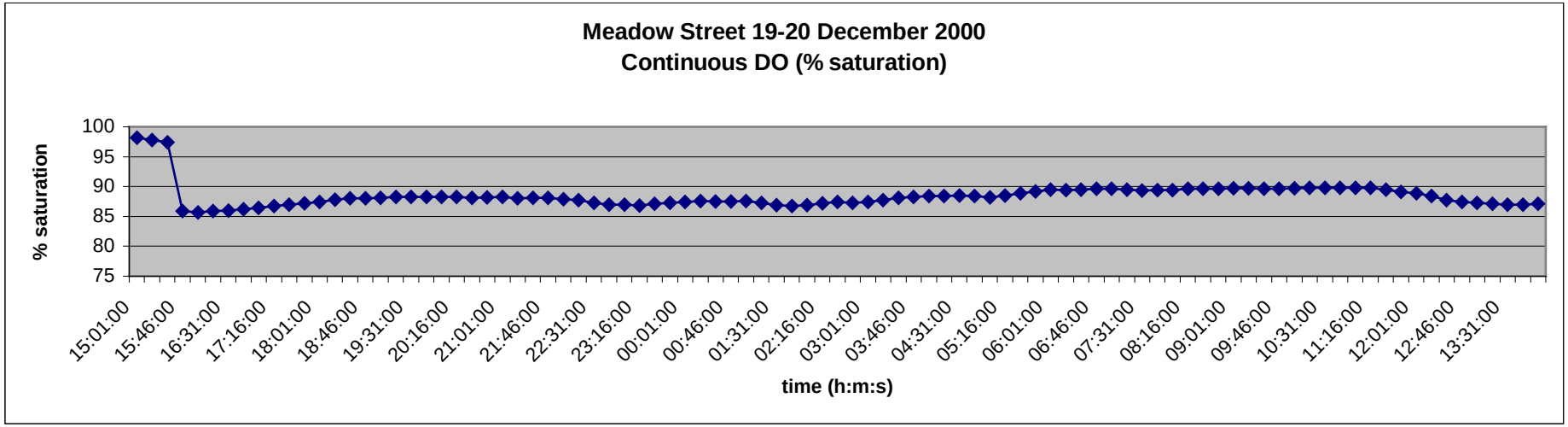


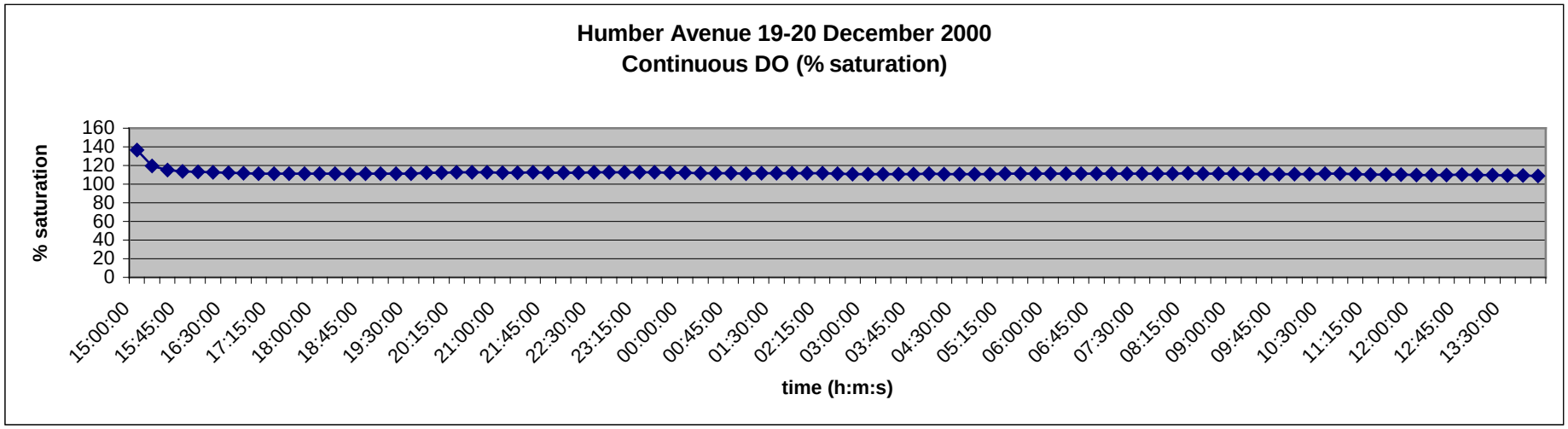
rain	Dry period	rain	Dry period

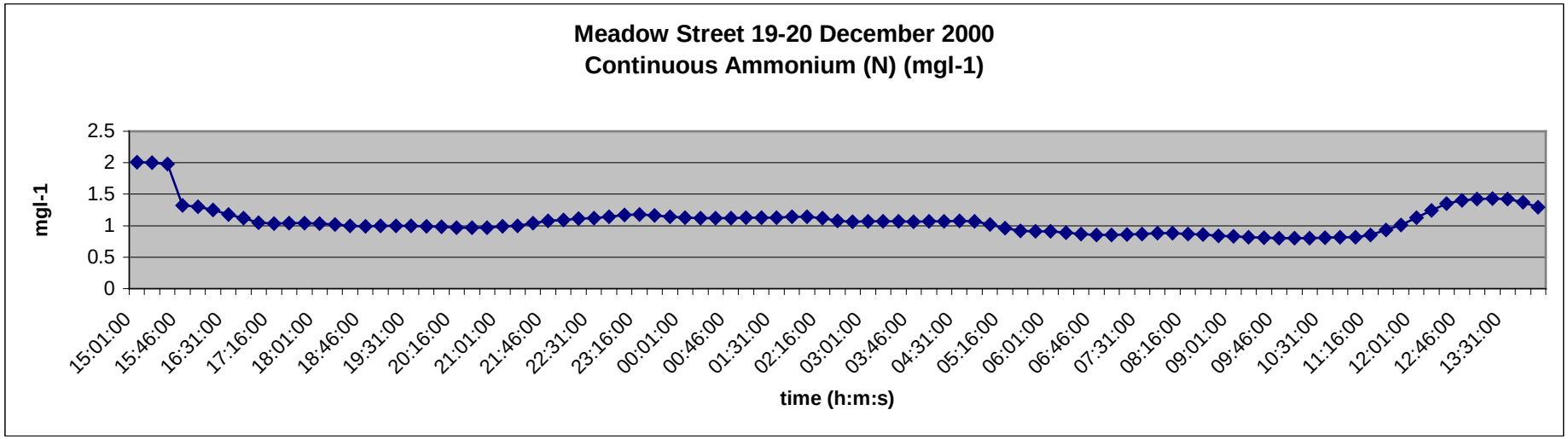
k) Nickel

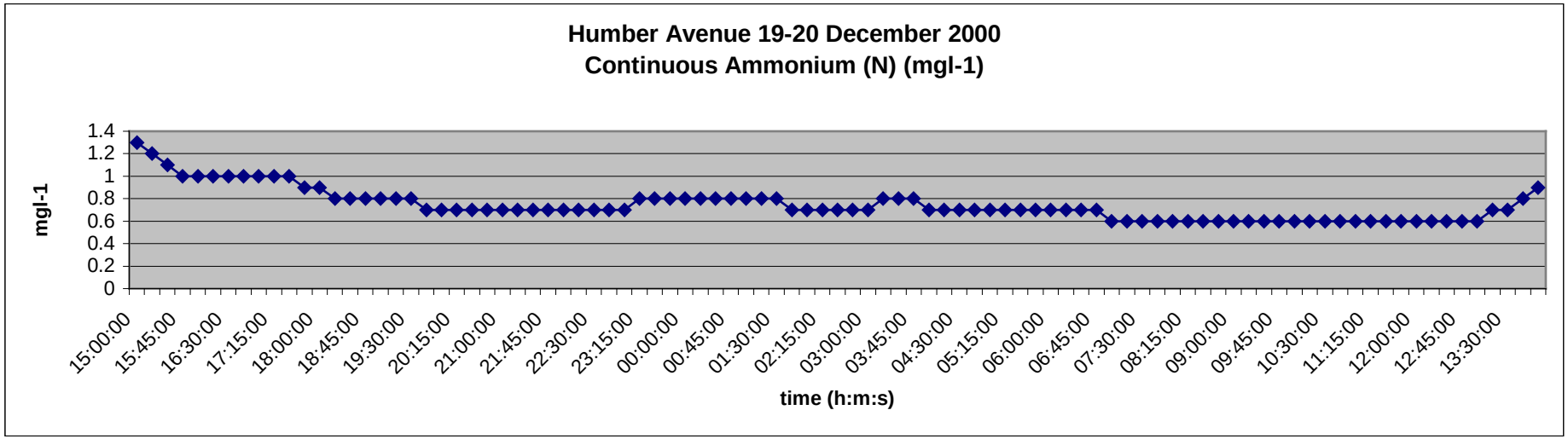


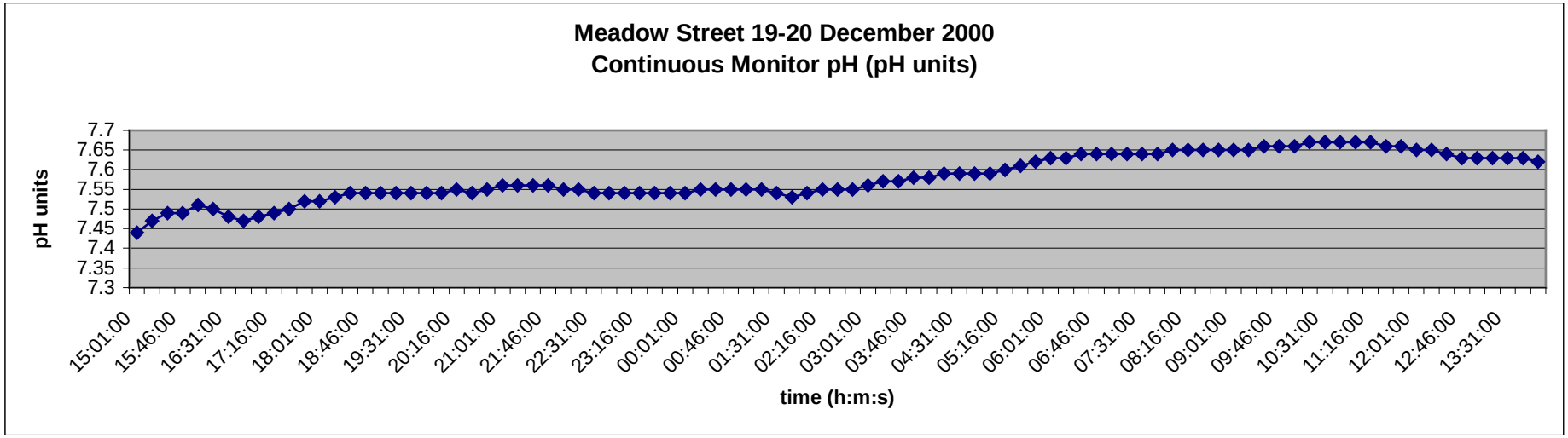
Auto7 Continuous monitors 19- 20 December 2000

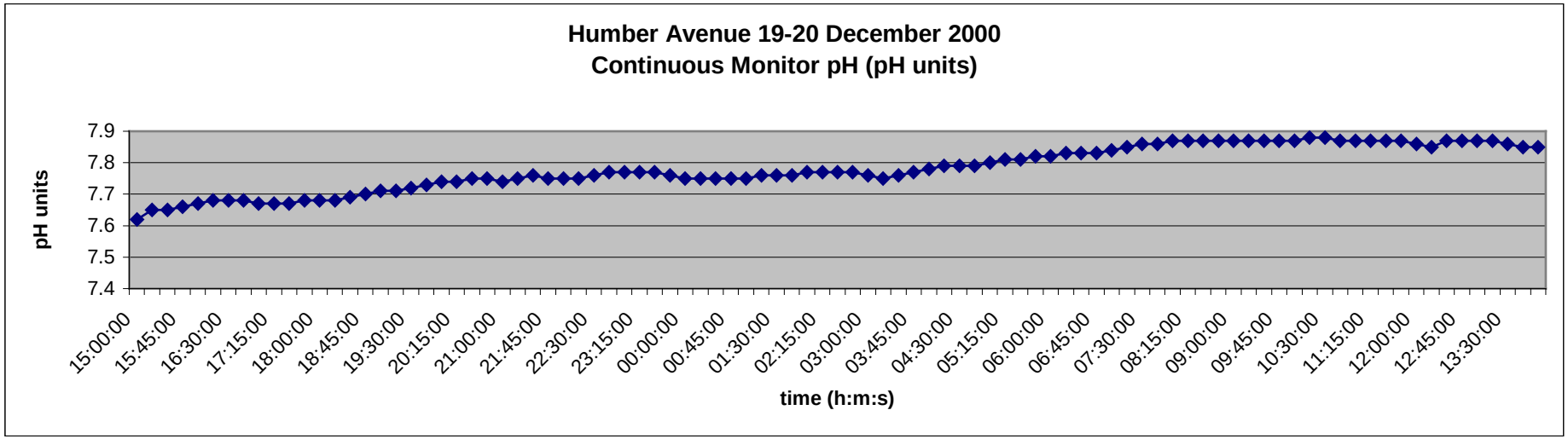


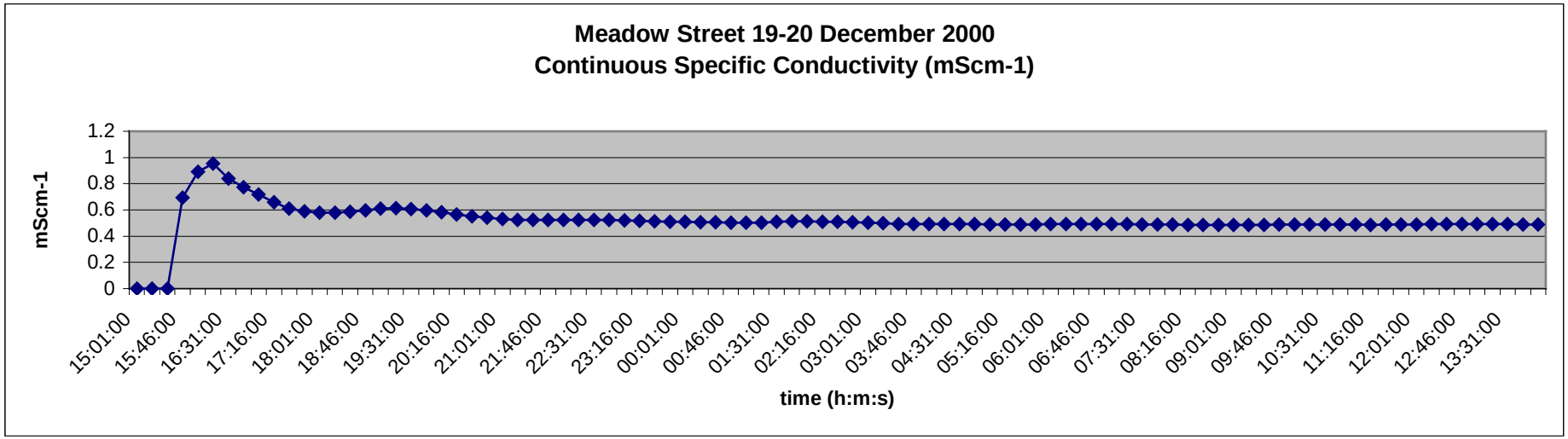


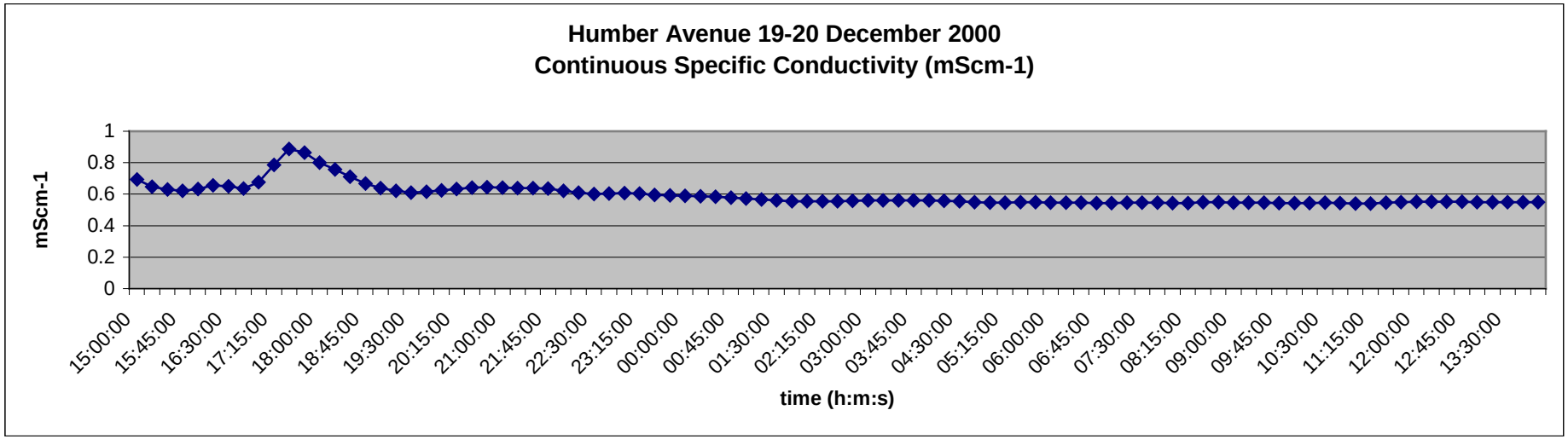

Meadow Street 19-20 December 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
2.5
2
1.5
1
0.5
0
15:01:00
15:46:00
16:31:00
17:16:00
18:01:00
18:46:00
19:31:00
20:16:00
21:01:00
21:46:00
22:31:00
23:16:00
00:01:00
00:46:00
01:31:00
02:16:00
03:01:00
03:46:00
04:31:00
05:16:00
06:01:00
06:46:00
07:31:00
08:16:00
09:01:00
09:46:00
10:31:00
11:16:00
12:01:00
12:46:00
13:31:00
time (h:m:s)


Humber Avenue 19-20 December 2000
Continuous Ammonium (N) (mgl-1)
mgl-1
1.4
1.2
1
0.8
0.6
0.4
0.2
0
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

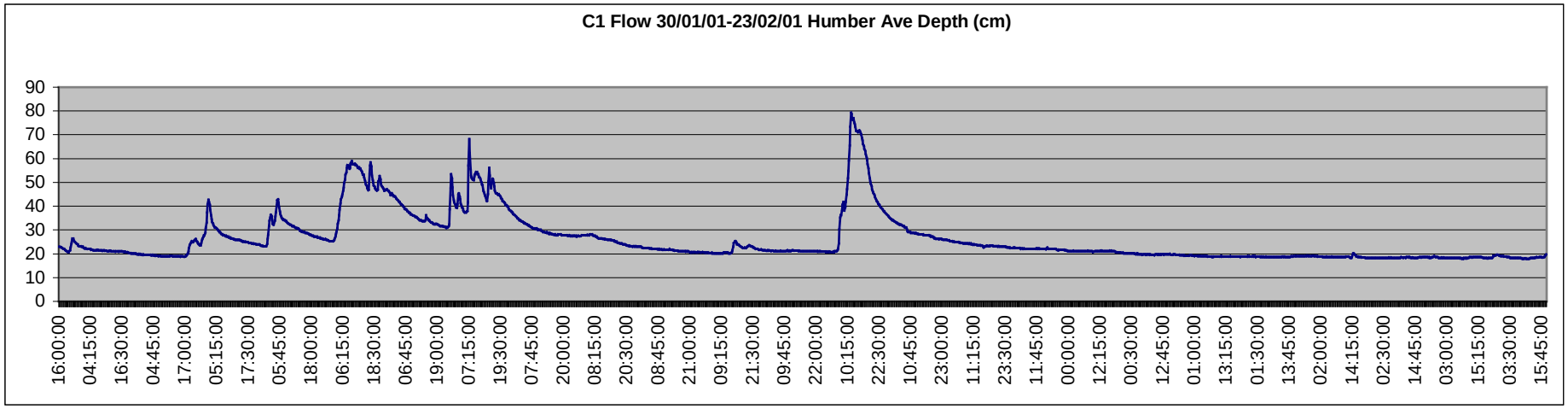

Meadow Street 19-20 December 2000
Continuous Monitor pH (pH units)
pH units
7.7
7.65
7.6
7.55
7.5
7.45
7.4
7.35
7.3
15:01:00
15:46:00
16:31:00
17:16:00
18:01:00
18:46:00
19:31:00
20:16:00
21:01:00
21:46:00
22:31:00
23:16:00
00:01:00
00:46:00
01:31:00
02:16:00
03:01:00
03:46:00
04:31:00
05:16:00
06:01:00
06:46:00
07:31:00
08:16:00
09:01:00
09:46:00
10:31:00
11:16:00
12:01:00
12:46:00
13:31:00
time (h:m:s)

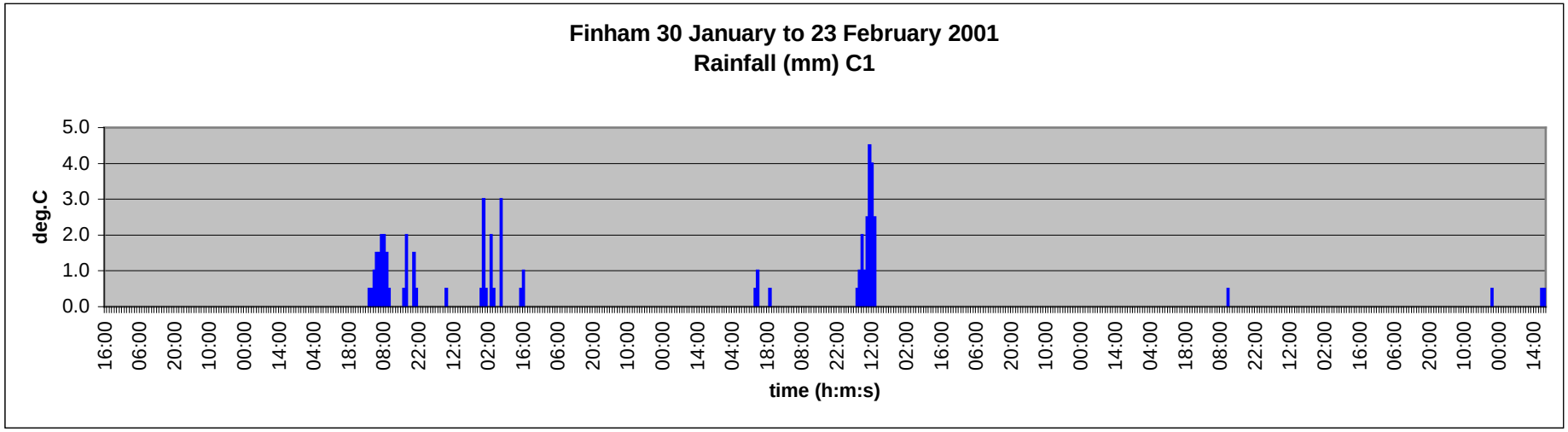

Humber Avenue 19-20 December 2000
Continuous Monitor pH (pH units)
pH units
7.9
7.8
7.7
7.6
7.5
7.4
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

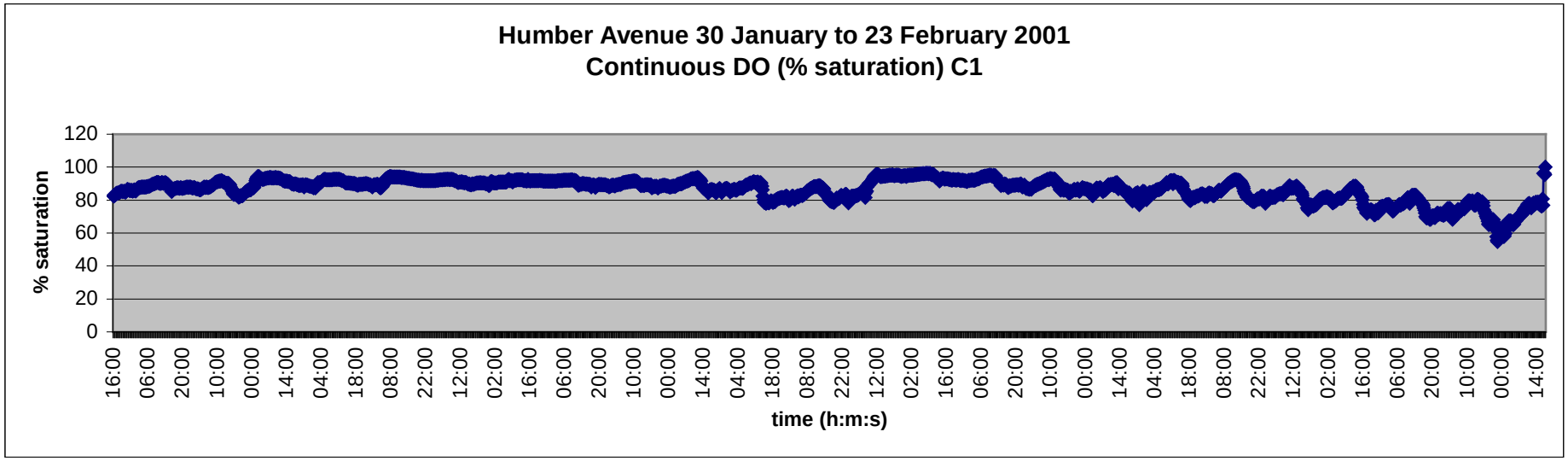

Meadow Street 19-20 December 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
1.2
1
0.8
0.6
0.4
0.2
0
15:01:00
15:46:00
16:31:00
17:16:00
18:01:00
18:46:00
19:31:00
20:16:00
21:01:00
21:46:00
22:31:00
23:16:00
00:01:00
00:46:00
01:31:00
02:16:00
03:01:00
03:46:00
04:31:00
05:16:00
06:01:00
06:46:00
07:31:00
08:16:00
09:01:00
09:46:00
10:31:00
11:16:00
12:01:00
12:46:00
13:31:00
time (h:m:s)

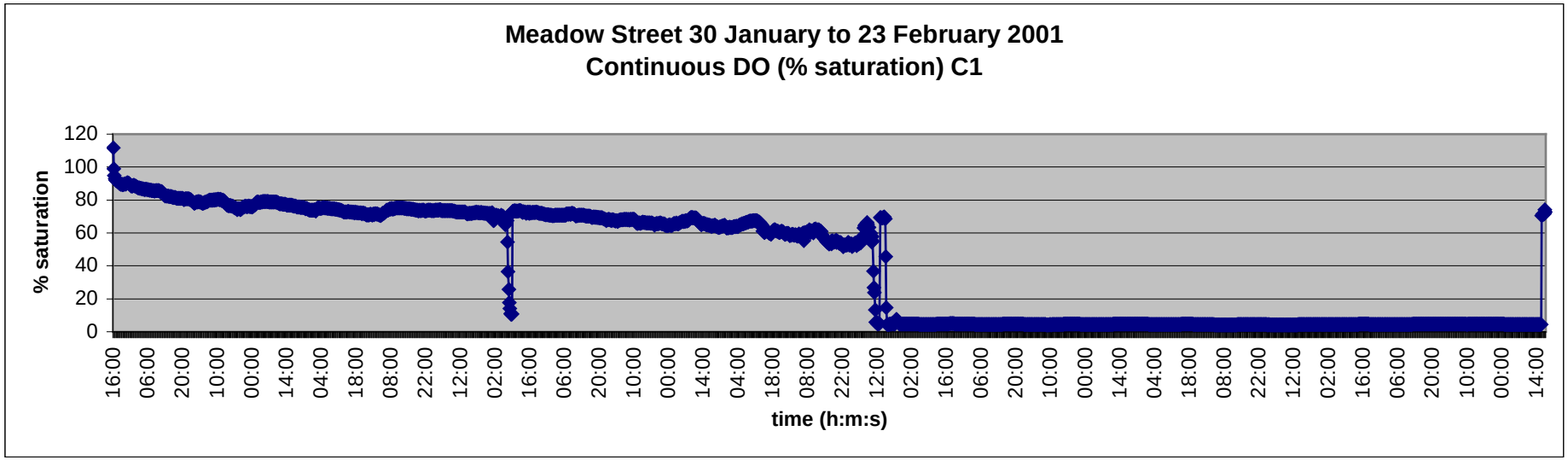

Humber Avenue 19-20 December 2000
Continuous Specific Conductivity (mScm-1)
mScm-1
1
0.8
0.6
0.4
0.2
0
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

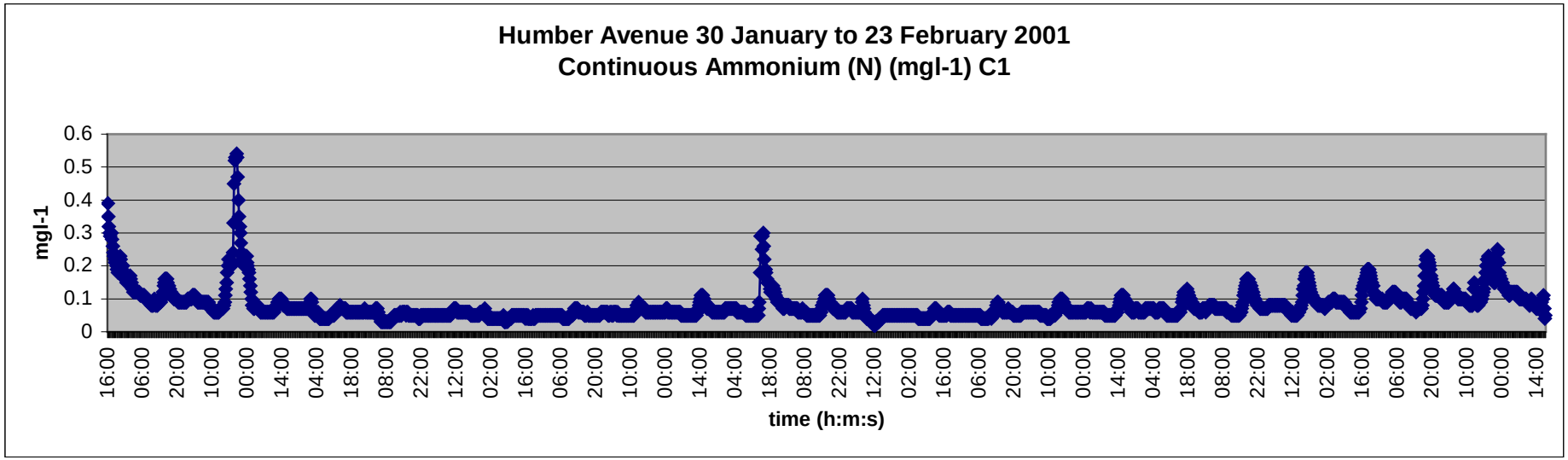
C1 Depth and Continuous monitors

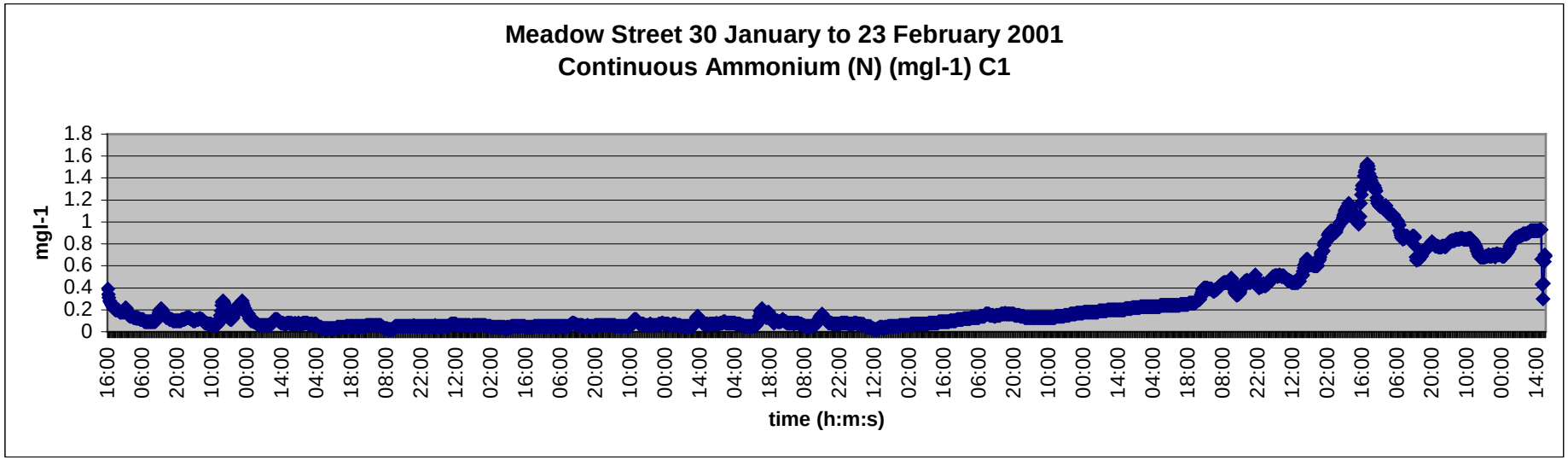


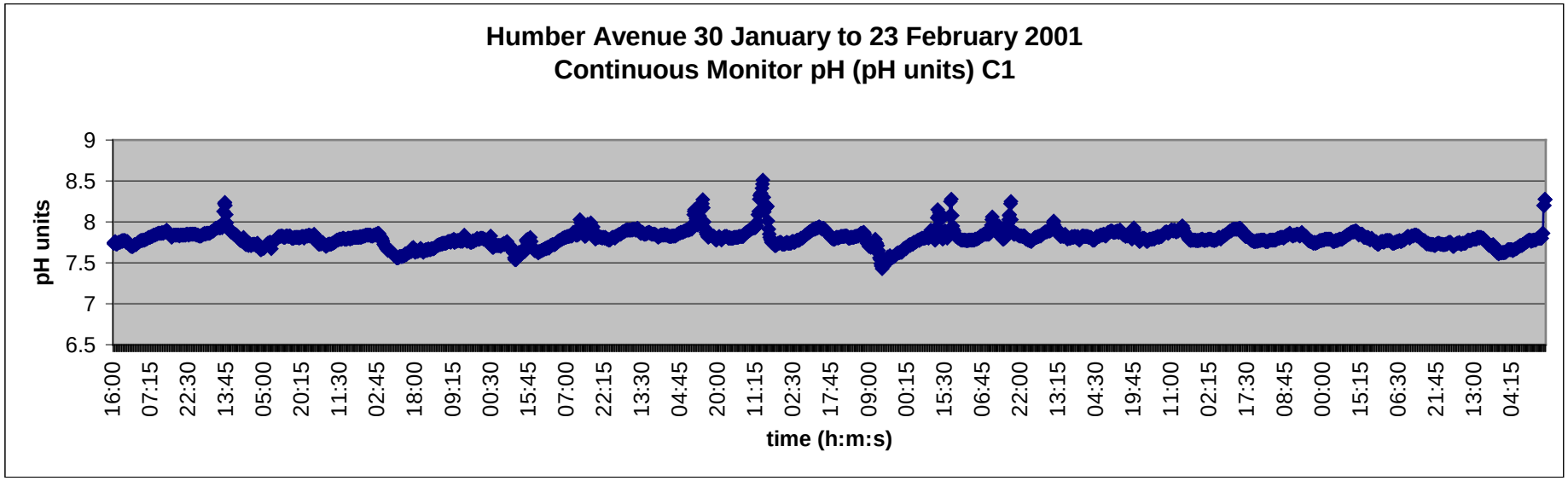


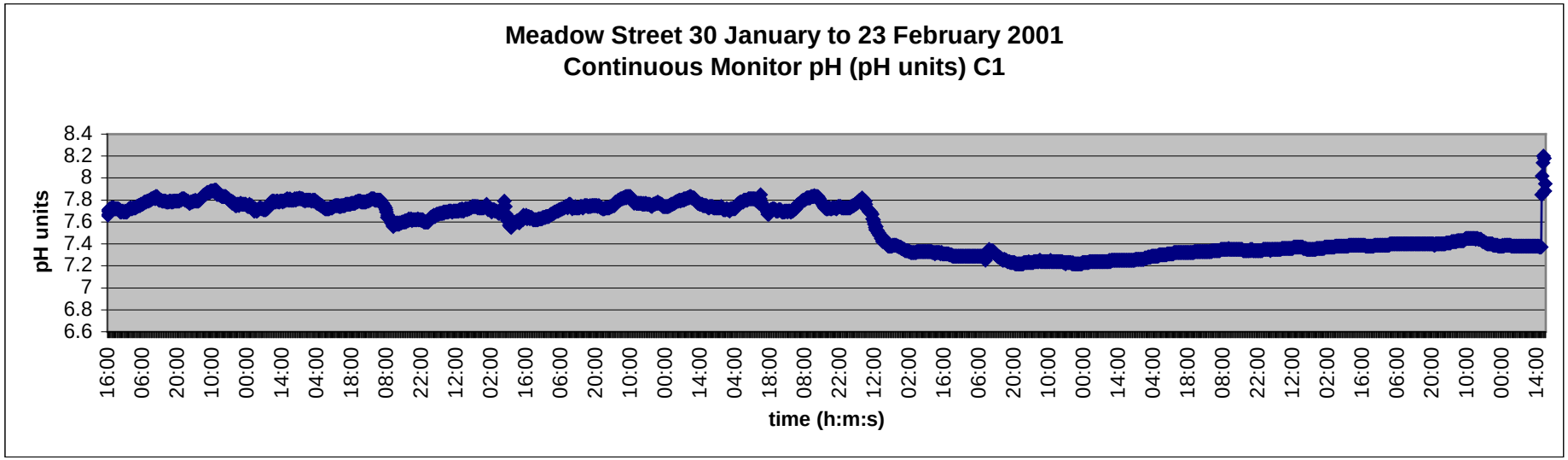

Humber Avenue 30 January to 23 February 2001
Continuous DO (% saturation) C1
% saturation
120
100
80
60
40
20
0
16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00
time (h:m:s)

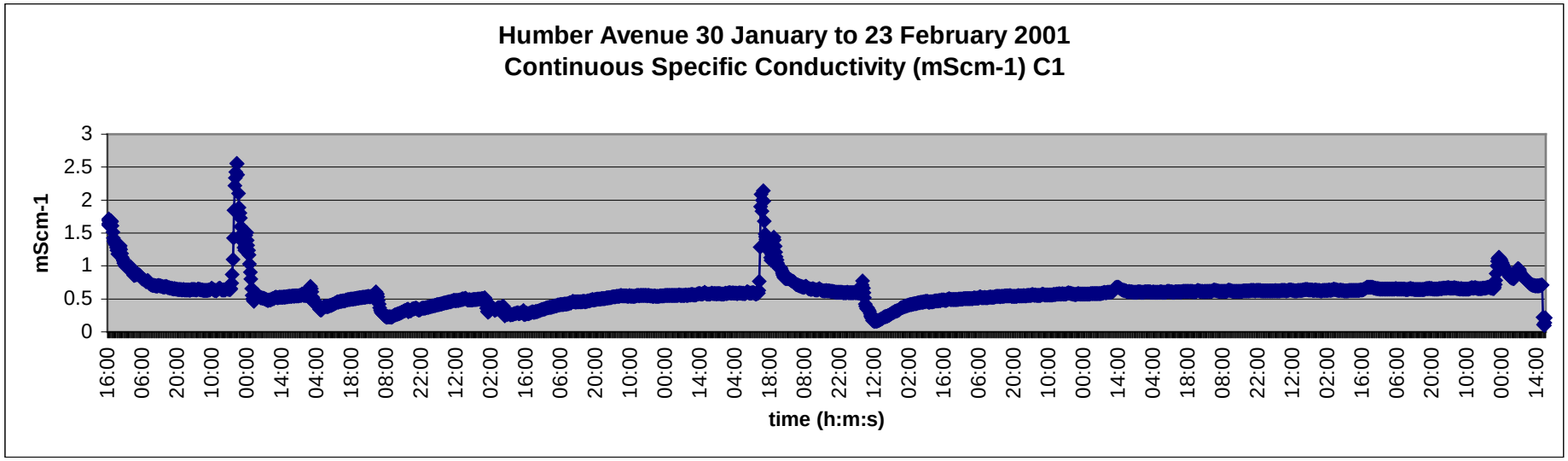

Meadow Street 30 January to 23 February 2001
Continuous DO (% saturation) C1
% saturation
120
100
80
60
40
20
0
16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00
time (h:m:s)

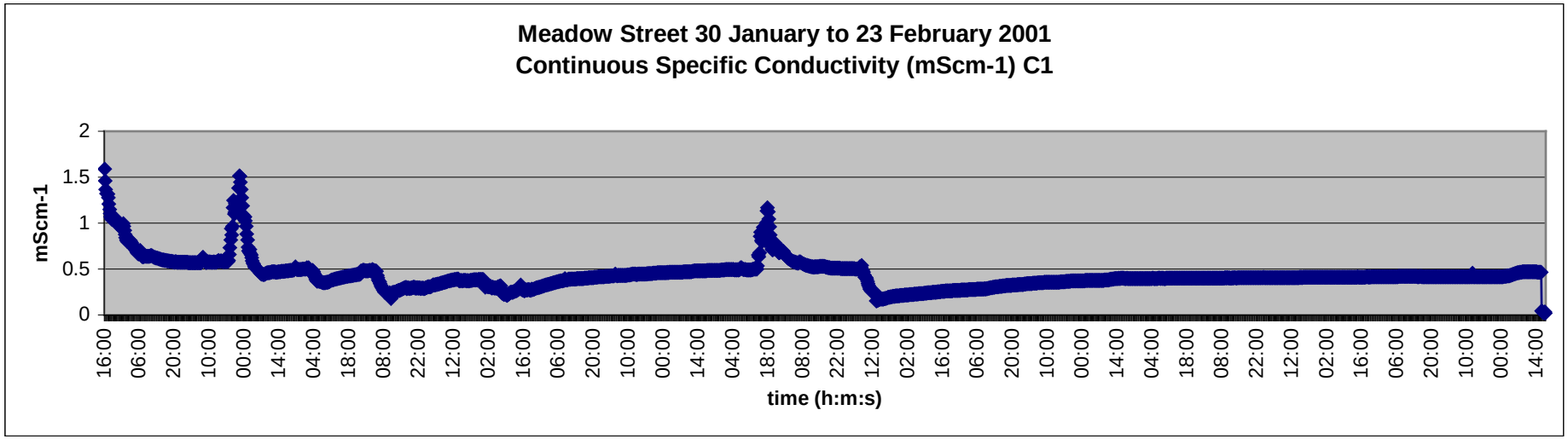

Humber Avenue 30 January to 23 February 2001
Continuous Ammonium (N) (mgl-1) C1
mgl-1
0.6
0.5
0.4
0.3
0.2
0.1
0
16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00
time (h:m:s)

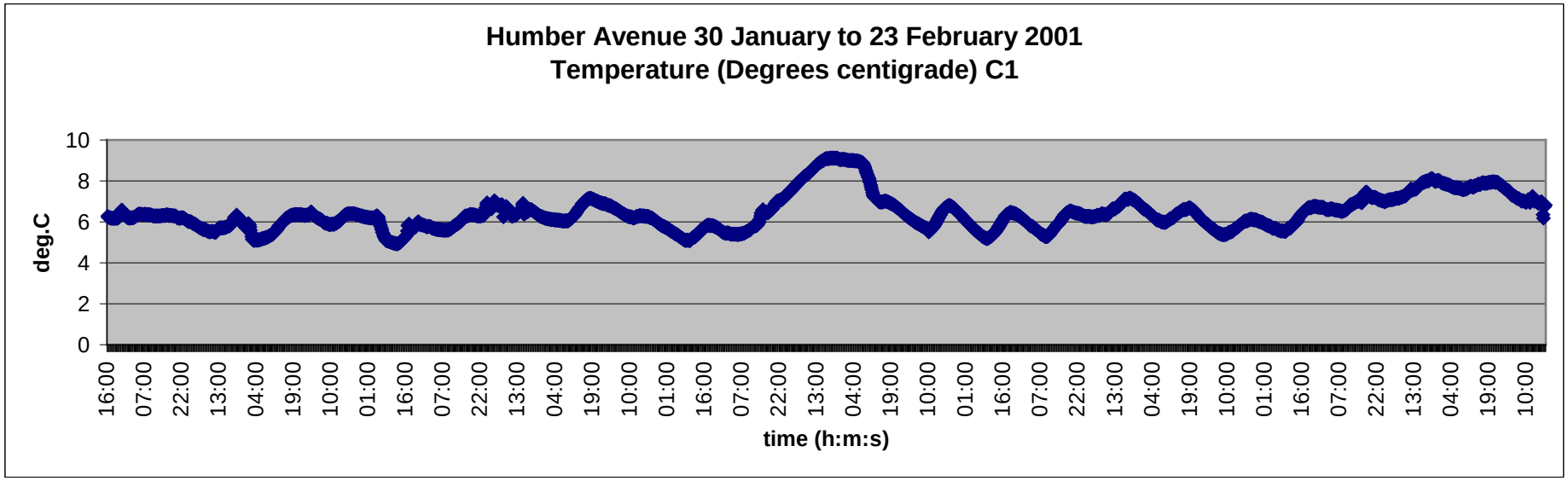

Meadow Street 30 January to 23 February 2001
Continuous Ammonium (N) (mgl-1) C1
mgl-1
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00
time (h:m:s)

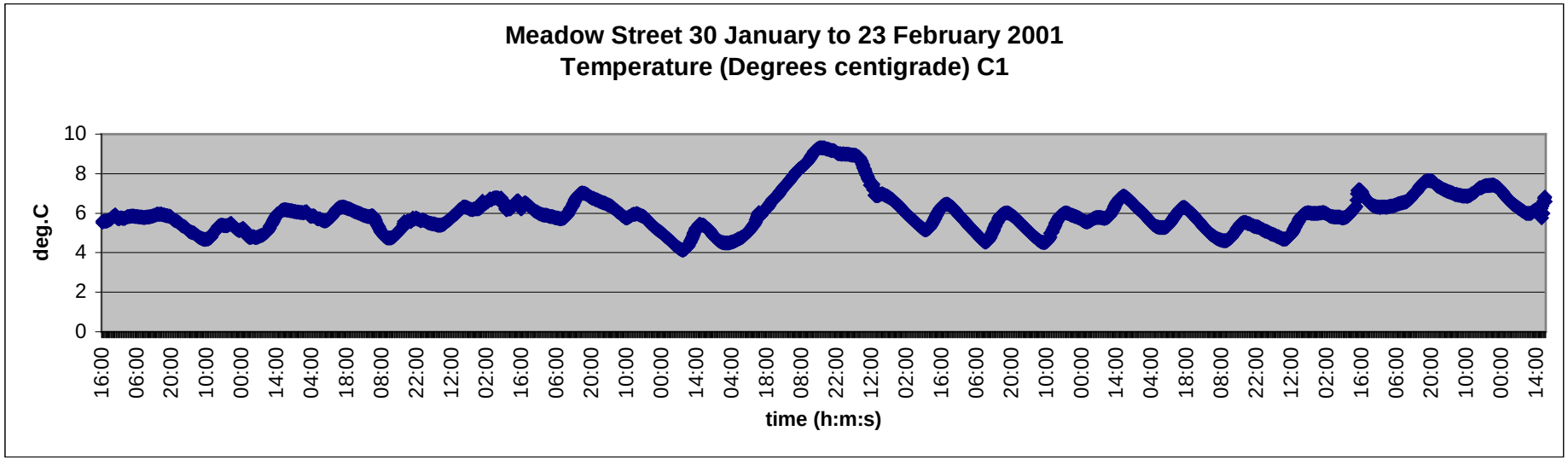

Humber Avenue 30 January to 23 February 2001
Continuous Monitor pH (pH units) C1
pH units
9
8.5
8
7.5
7
6.5
16:00
07:15
22:30
13:45
05:00
20:15
11:30
02:45
18:00
09:15
00:30
15:45
07:00
22:15
13:30
04:45
20:00
11:15
02:30
17:45
09:00
00:15
15:30
06:45
22:00
13:15
04:30
19:45
11:00
02:15
17:30
08:45
00:00
15:15
06:30
21:45
13:00
04:15
time (h:m:s)


Meadow Street 30 January to 23 February 2001
Continuous Monitor pH (pH units) C1
pH units
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
6.6
16:00
06:00
20:00
10:00
00:00
14:00
04:00
18:00
08:00
22:00
12:00
02:00
16:00
06:00
20:00
10:00
00:00
14:00
04:00
18:00
08:00
22:00
12:00
02:00
16:00
06:00
20:00
10:00
00:00
14:00
04:00
18:00
08:00
22:00
12:00
02:00
16:00
06:00
20:00
10:00
00:00
14:00
time (h:m:s)


Humber Avenue 30 January to 23 February 2001
Continuous Specific Conductivity (mScm-1) C1
mScm-1
3
2.5
2
1.5
1
0.5
0
16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00
time (h:m:s)

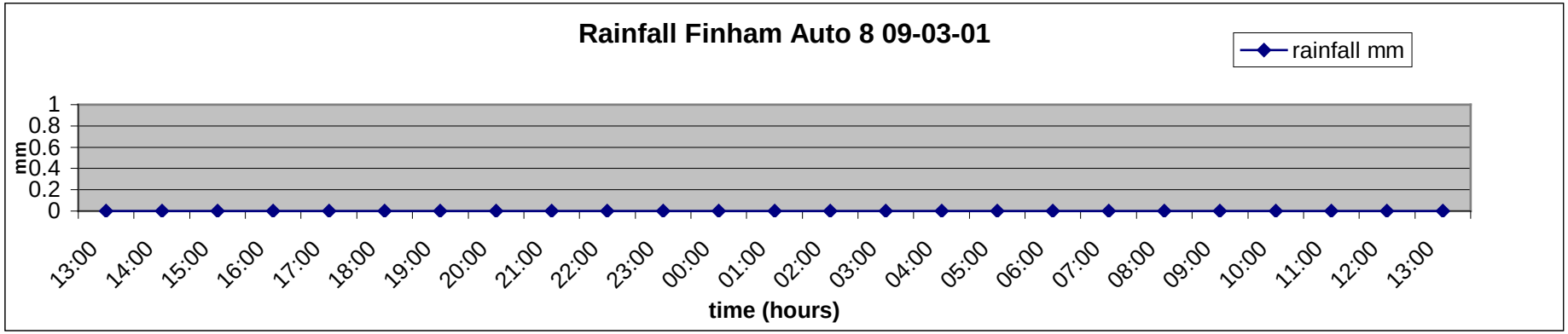

Meadow Street 30 January to 23 February 2001
Continuous Specific Conductivity (mScm-1) C1
mScm-1
2
1.5
1
0.5
0
16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00
time (h:m:s)


Humber Avenue 30 January to 23 February 2001
Temperature (Degrees centigrade) C1
deg.C
10
8
6
4
2
0
16:00 07:00 22:00 13:00 04:00 19:00 10:00 01:00 16:00 07:00 22:00 13:00 04:00 19:00 10:00 01:00 16:00 07:00 22:00 13:00 04:00 19:00 10:00 01:00 16:00 07:00 22:00 13:00 04:00 19:00 10:00
time (h:m:s)


Meadow Street 30 January to 23 February 2001
Temperature (Degrees centigrade) C1
deg.C
10
8
6
4
2
0
16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00 04:00 18:00 08:00 22:00 12:00 02:00 16:00 06:00 20:00 10:00 00:00 14:00
time (h:m:s)

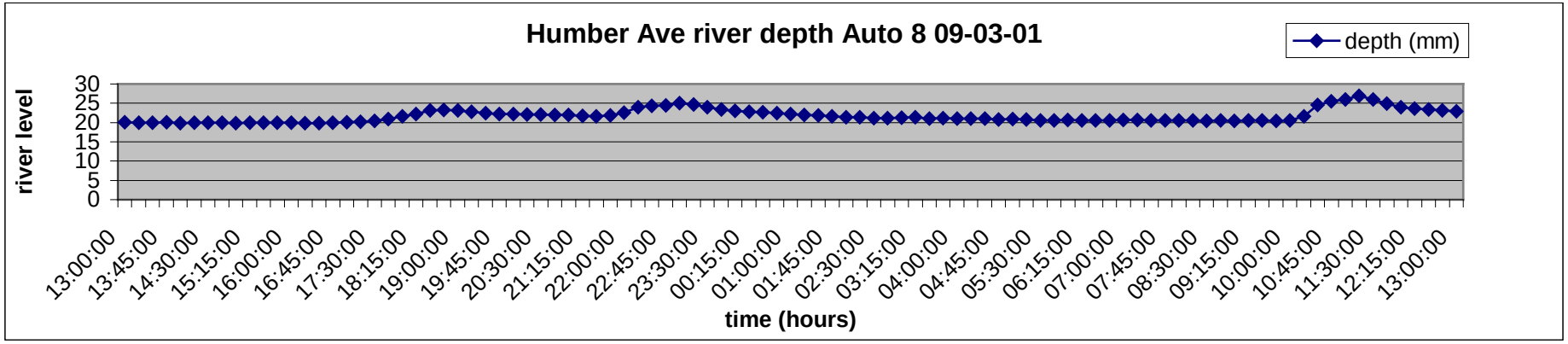
Auto 8 Humber Avenue 9-10 March 2001

a) Rainfall

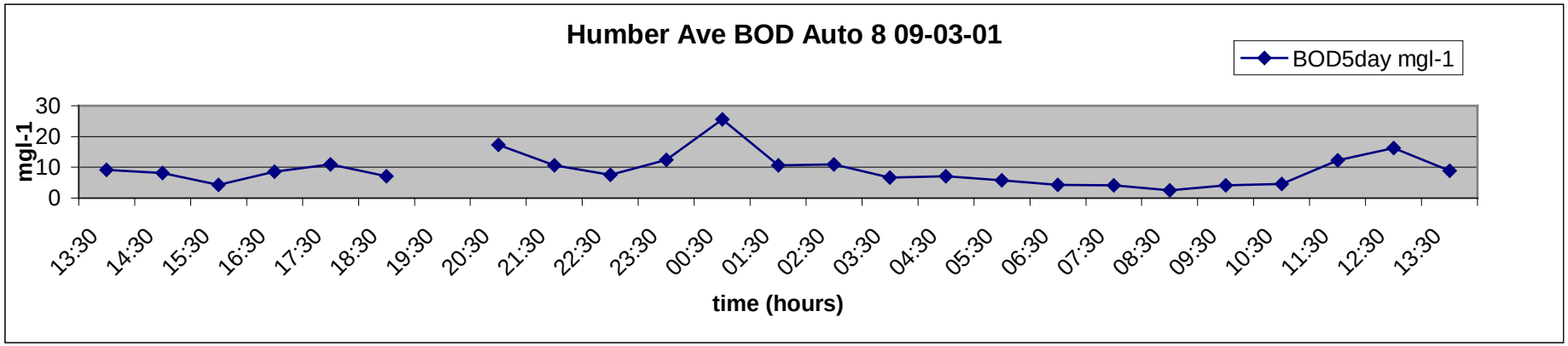


Dry period

ai) River Depth

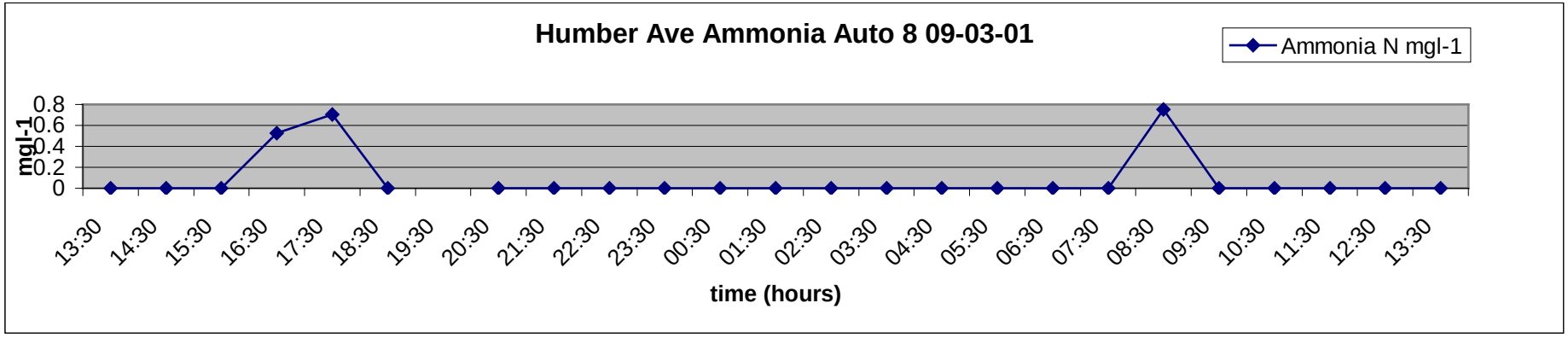


b) Biochemical Oxygen Demand (BOD)

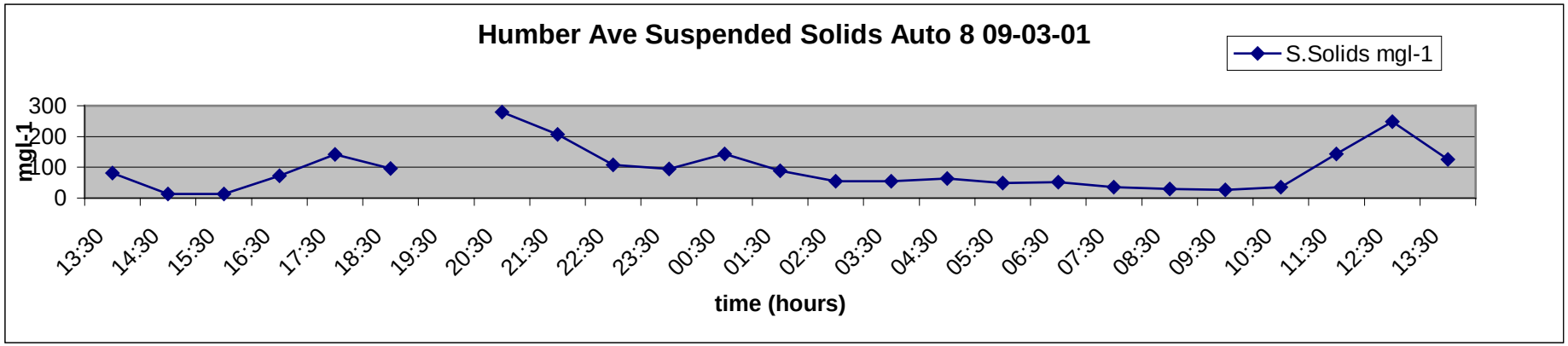


Dry period

c) Ammonia

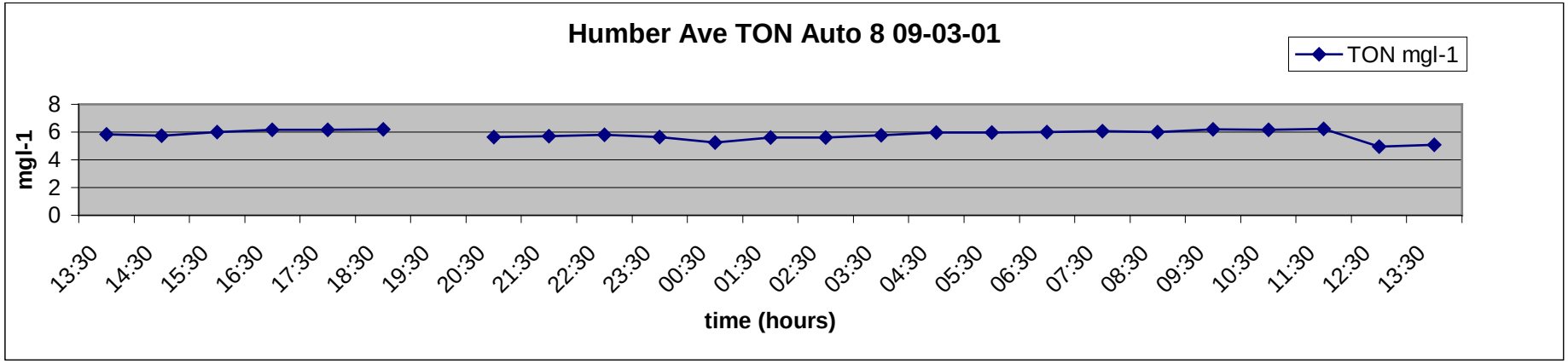


d) Suspended Solids

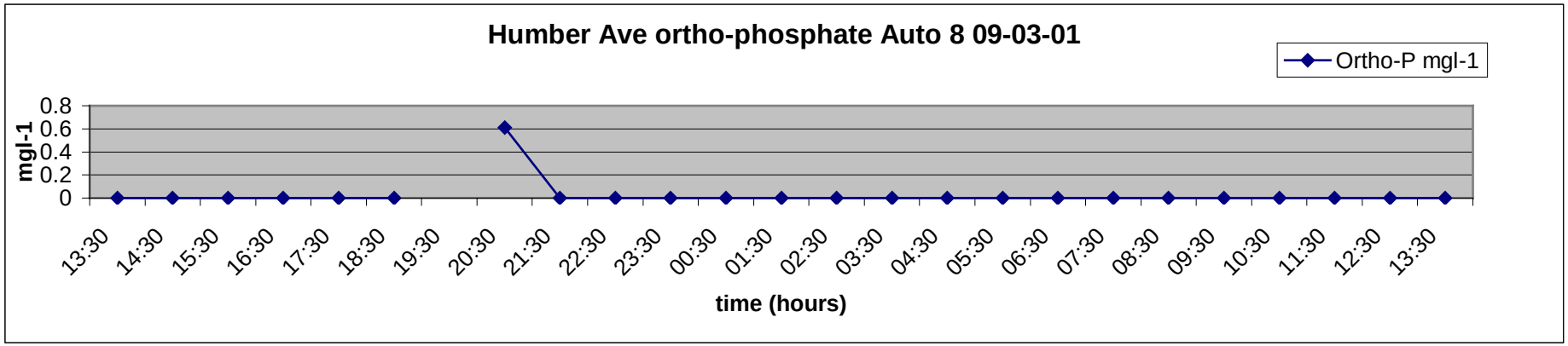


Dry period

e) Total Oxidised Nitrogen

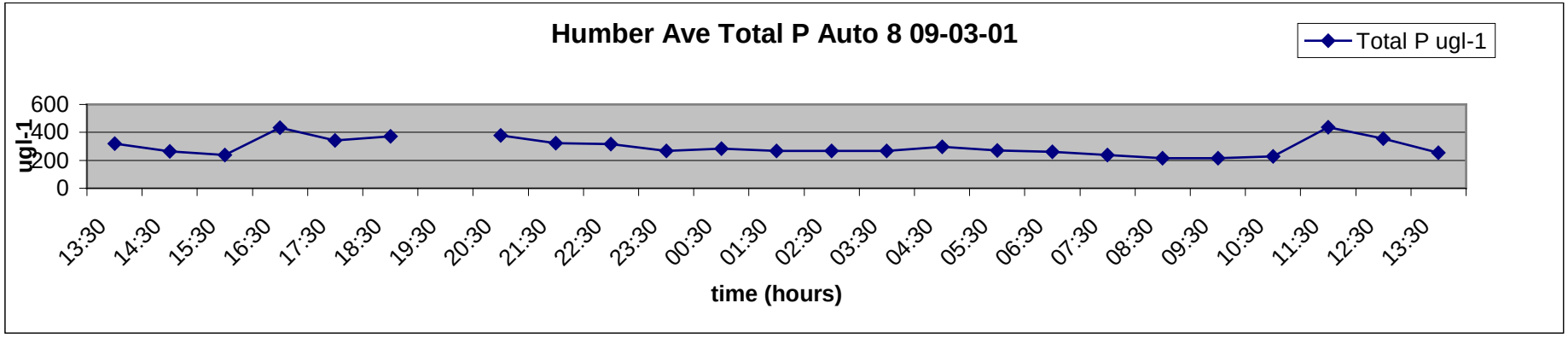


f) Ortho-phosphate

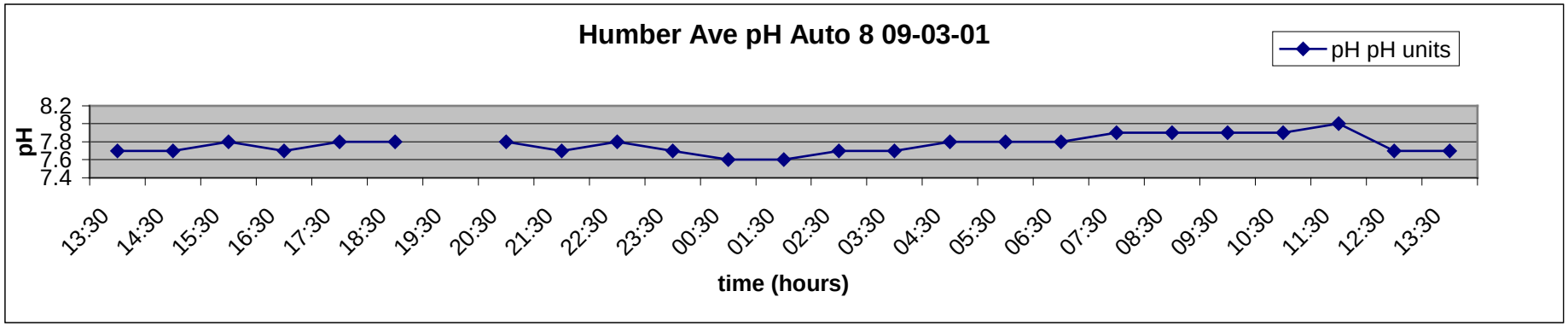


Dry period

g) Total Phosphate

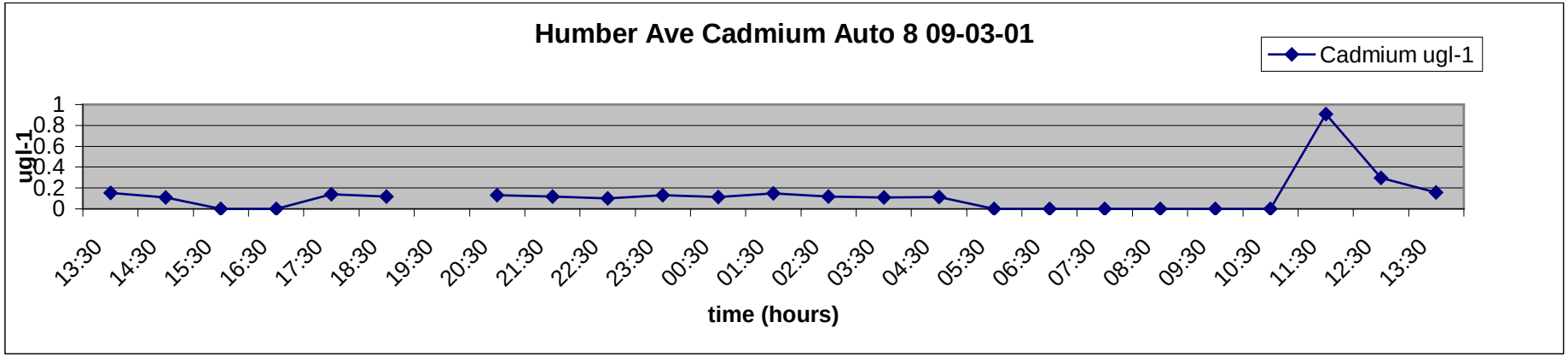


h) pH

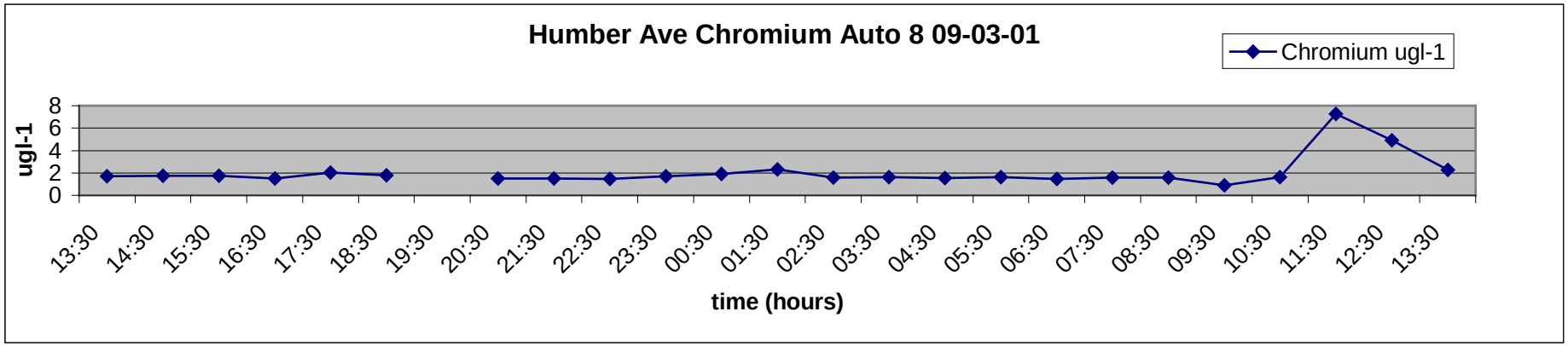


Dry period

i) Cadmium

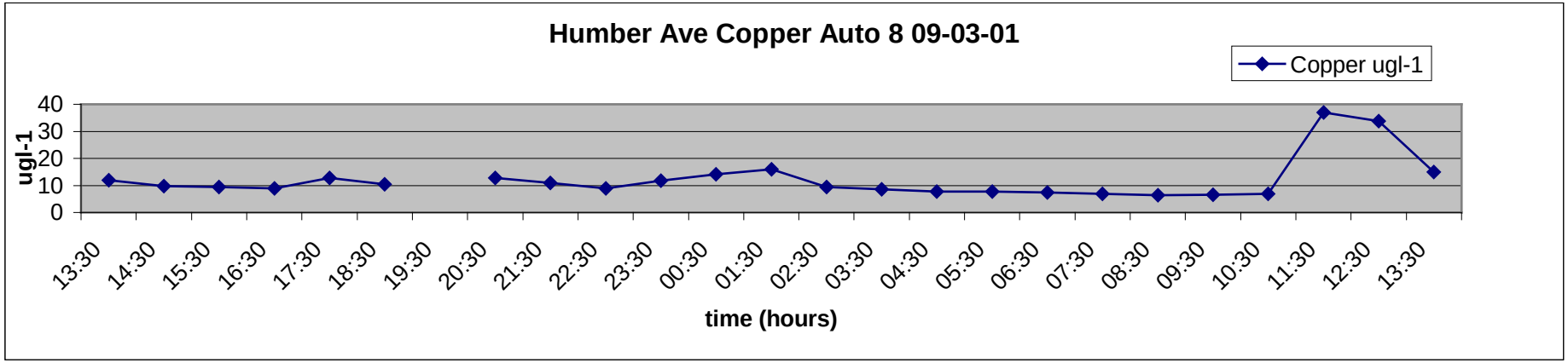


j) Chromium

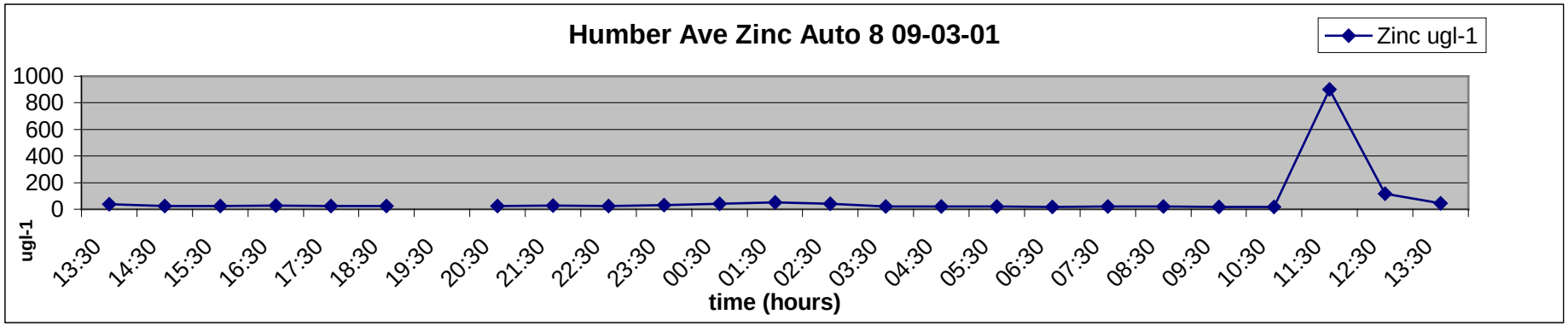


Dry period

k) Copper

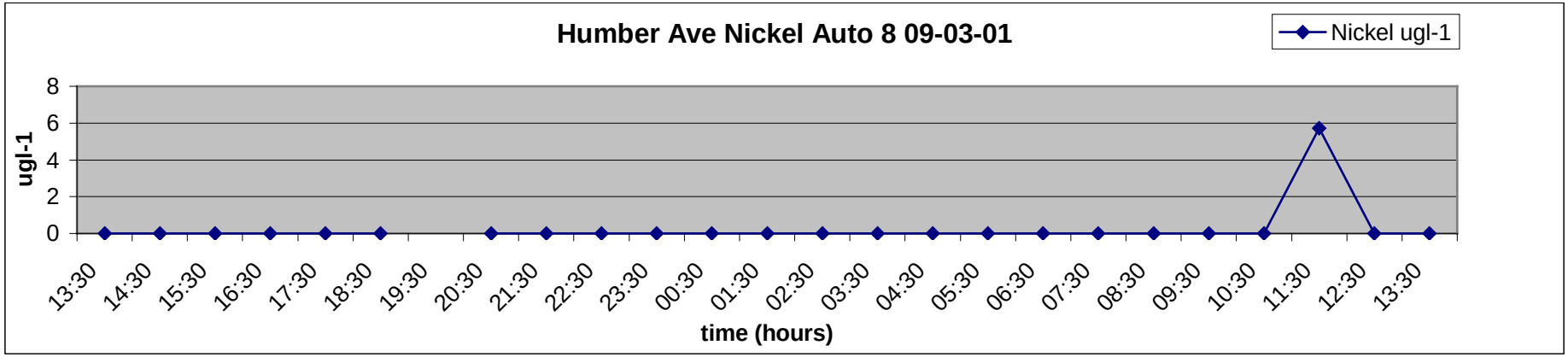


l) Zinc

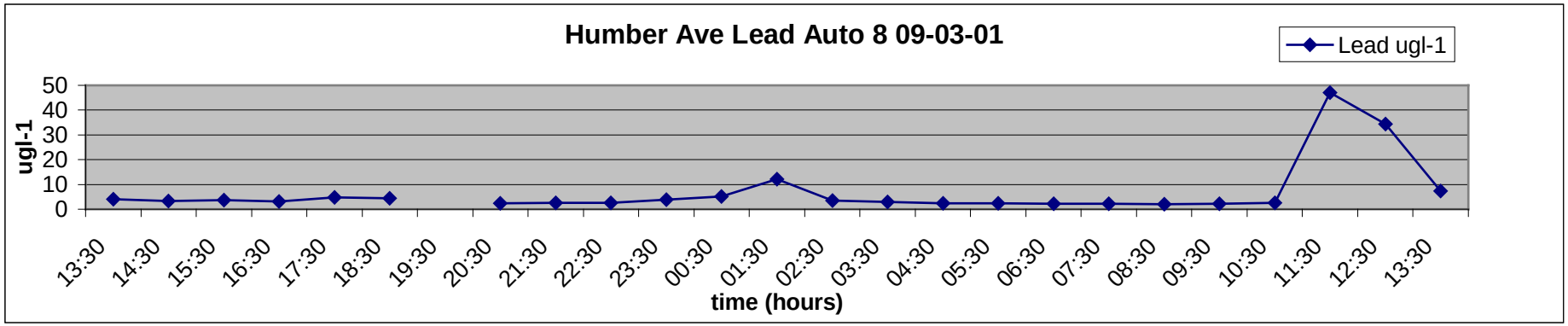


Dry period

m) Nickel

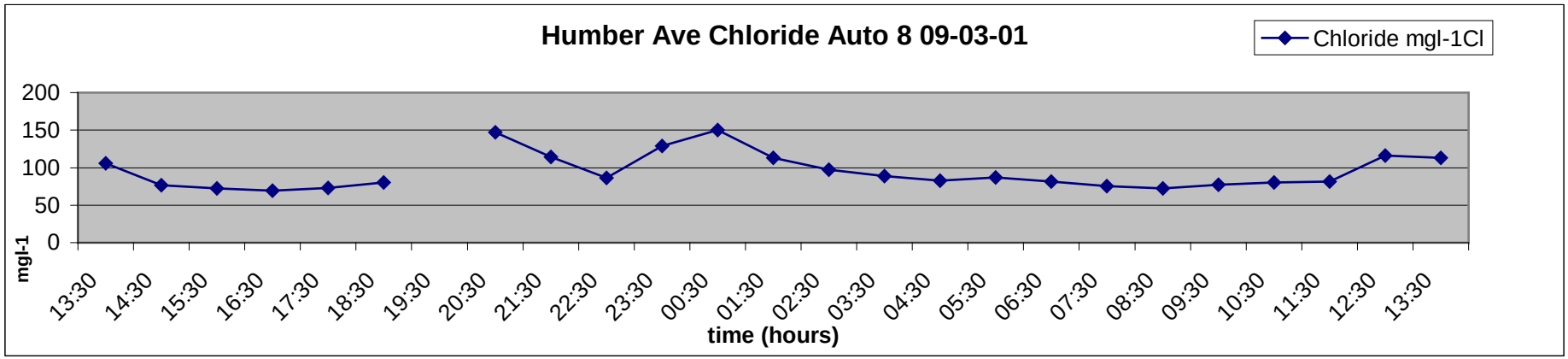


n) Lead

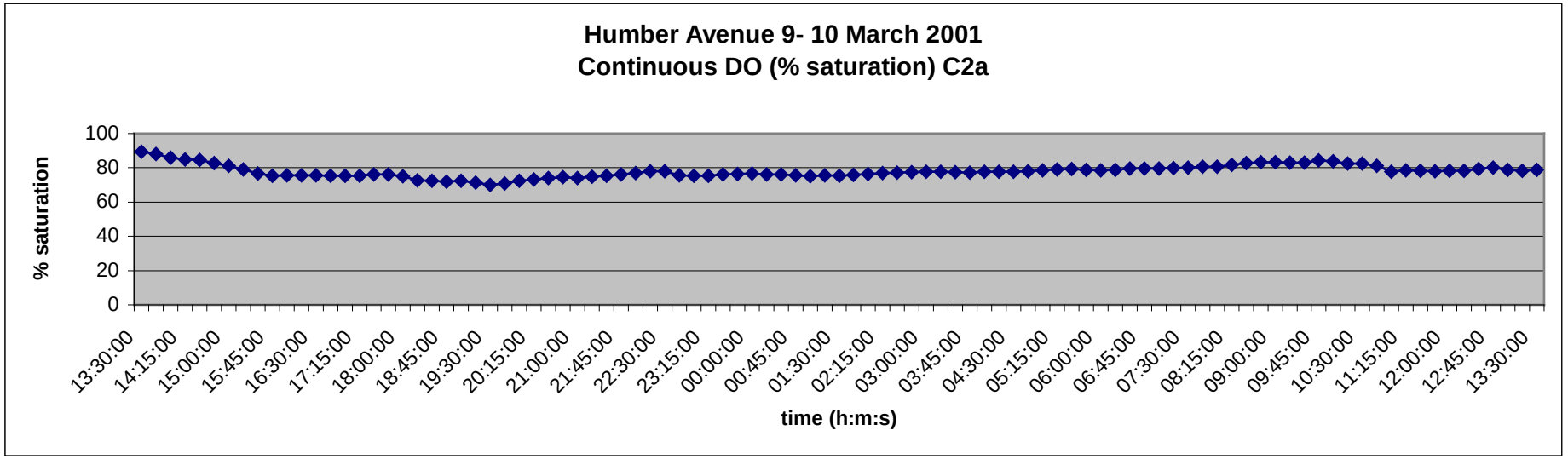


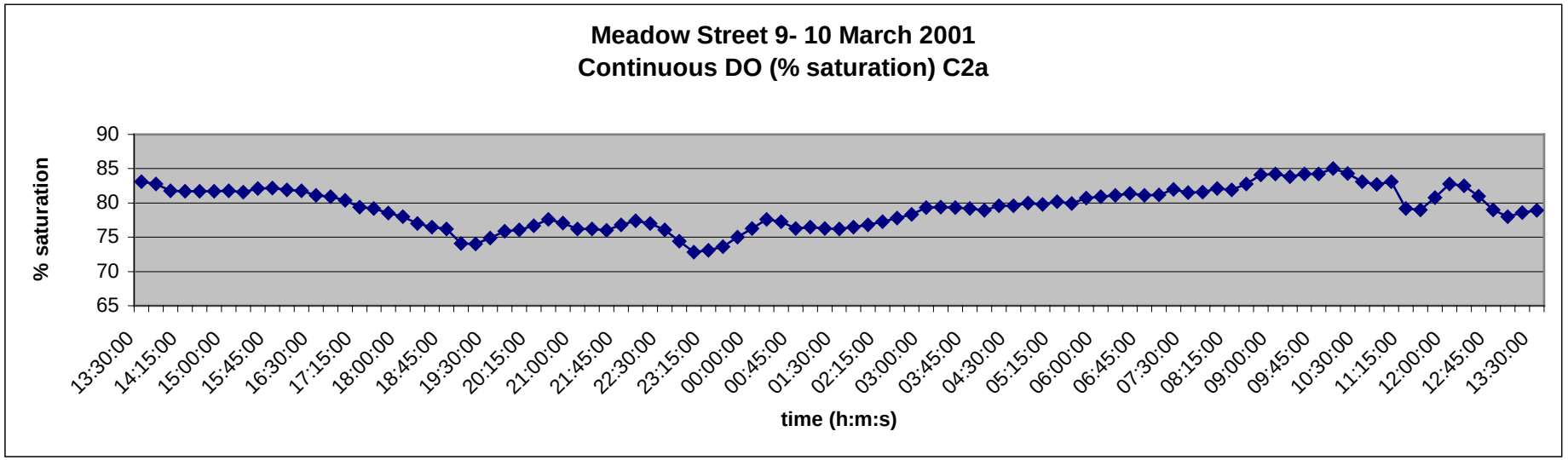
Dry period

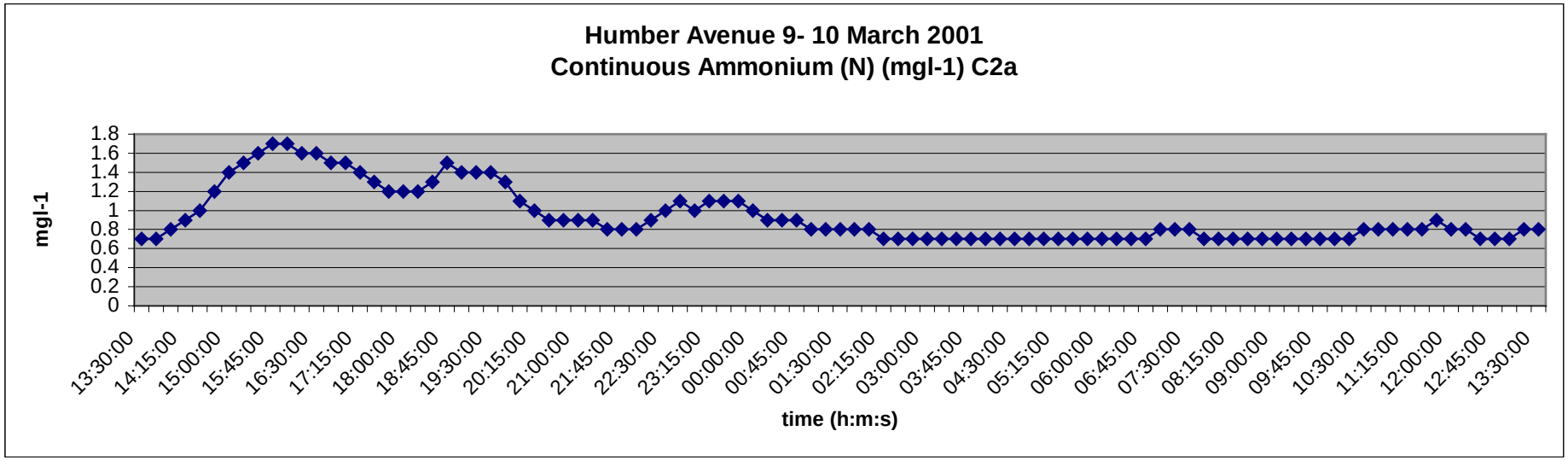
o) Chloride

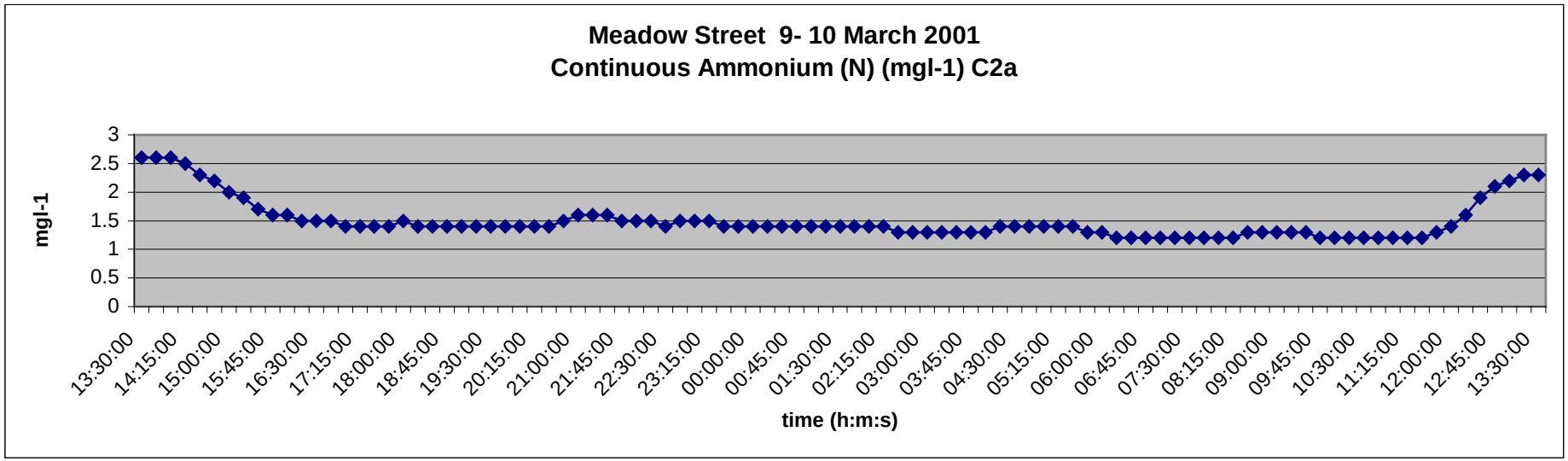


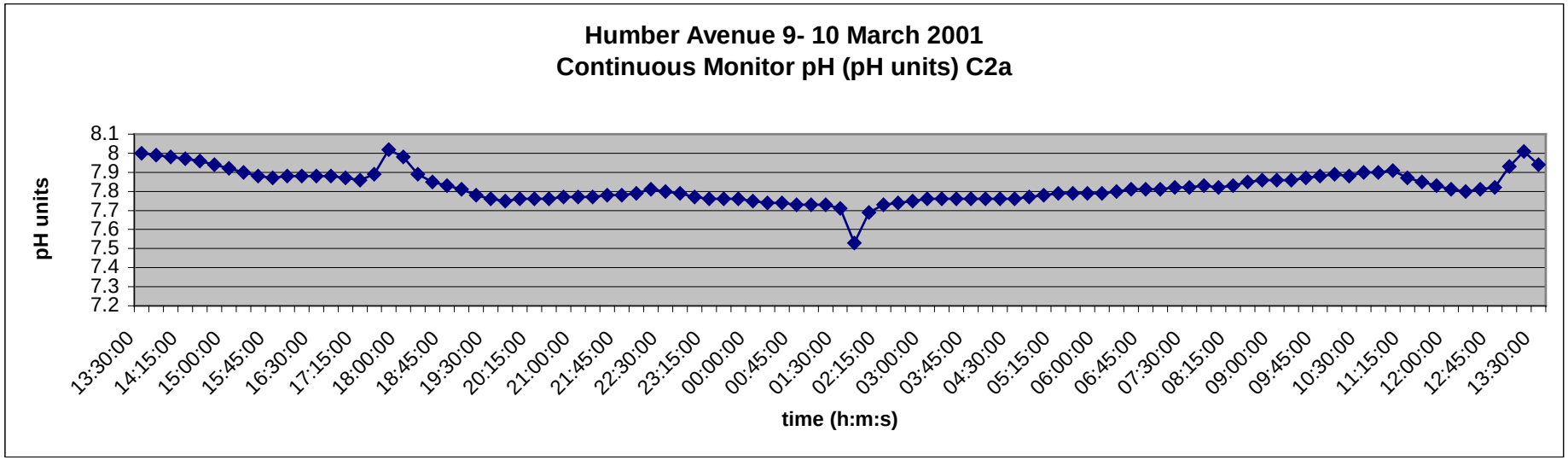
C2a Continuous monitor Results 9- 10 March 2001

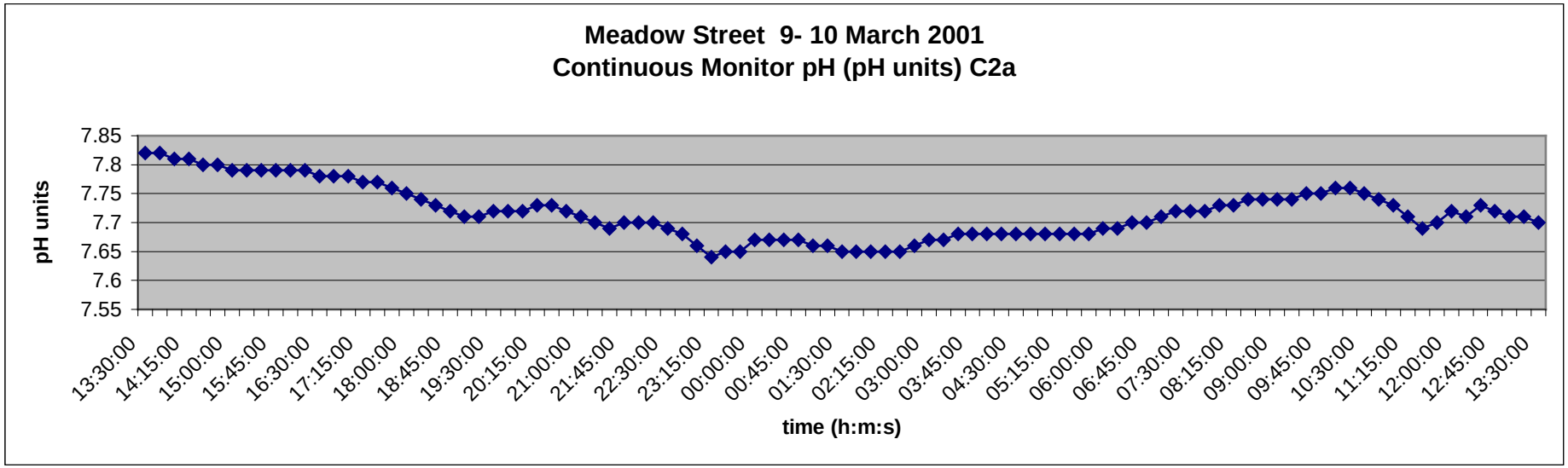


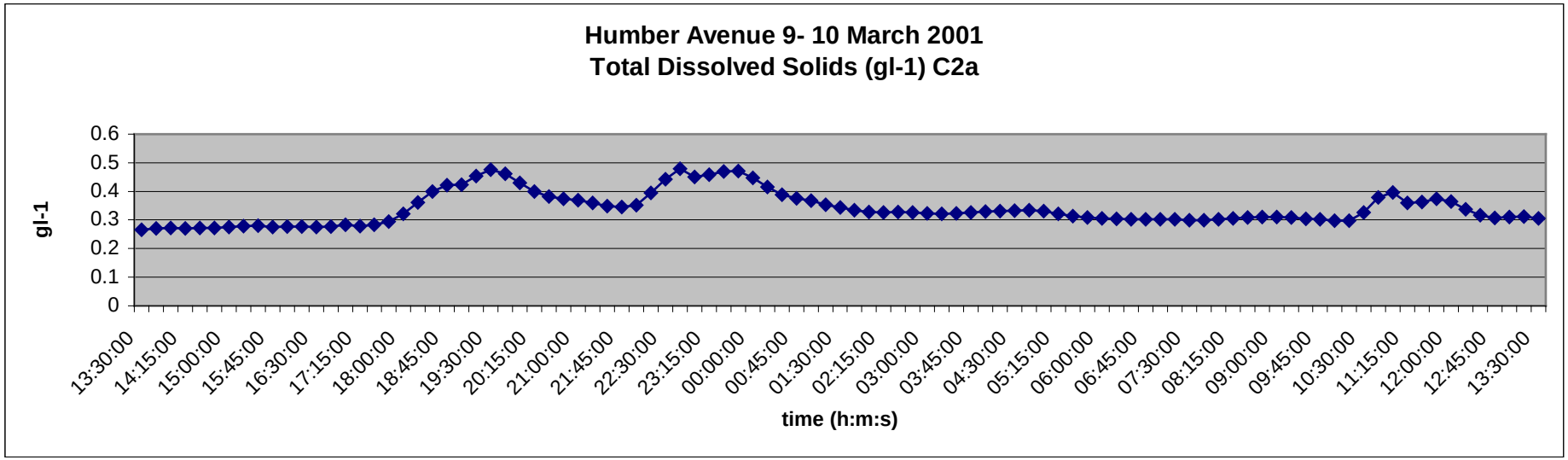


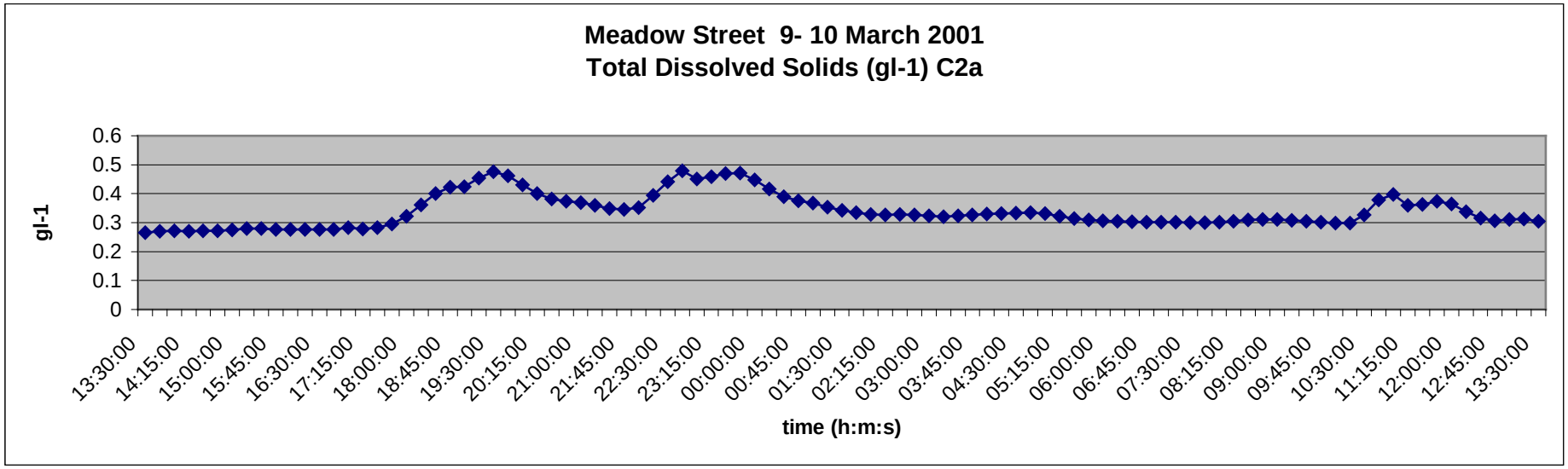

Humber Avenue 9- 10 March 2001
Continuous Ammonium (N) (mgl-1) C2a
mgl-1
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

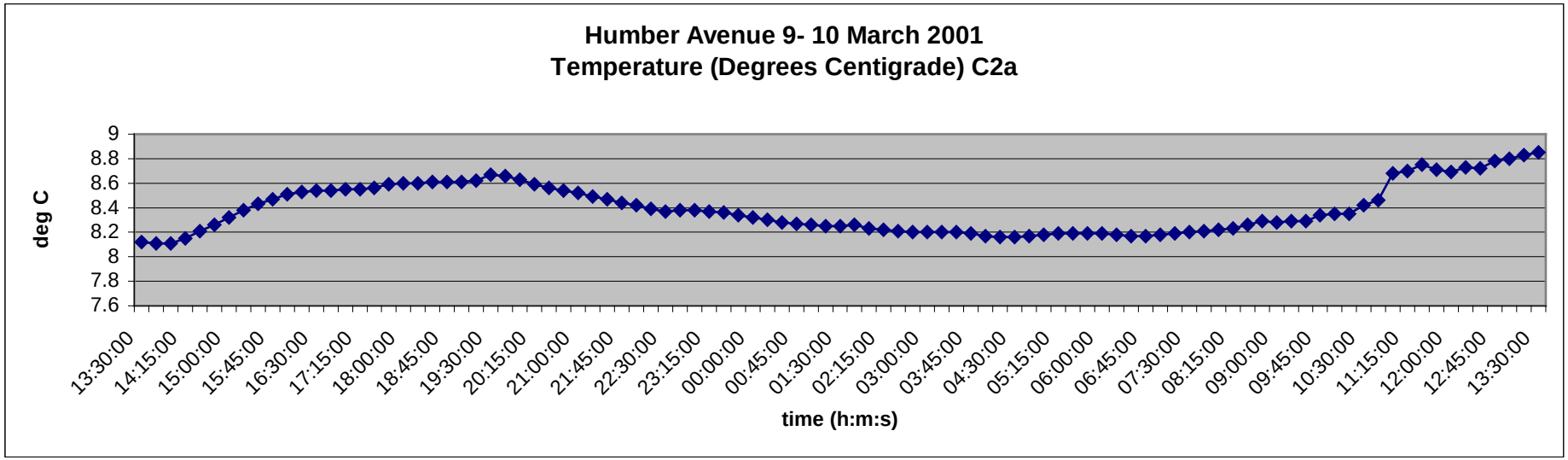

Meadow Street 9- 10 March 2001
Continuous Ammonium (N) (mgl-1) C2a
mgl-1
3
2.5
2
1.5
1
0.5
0
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

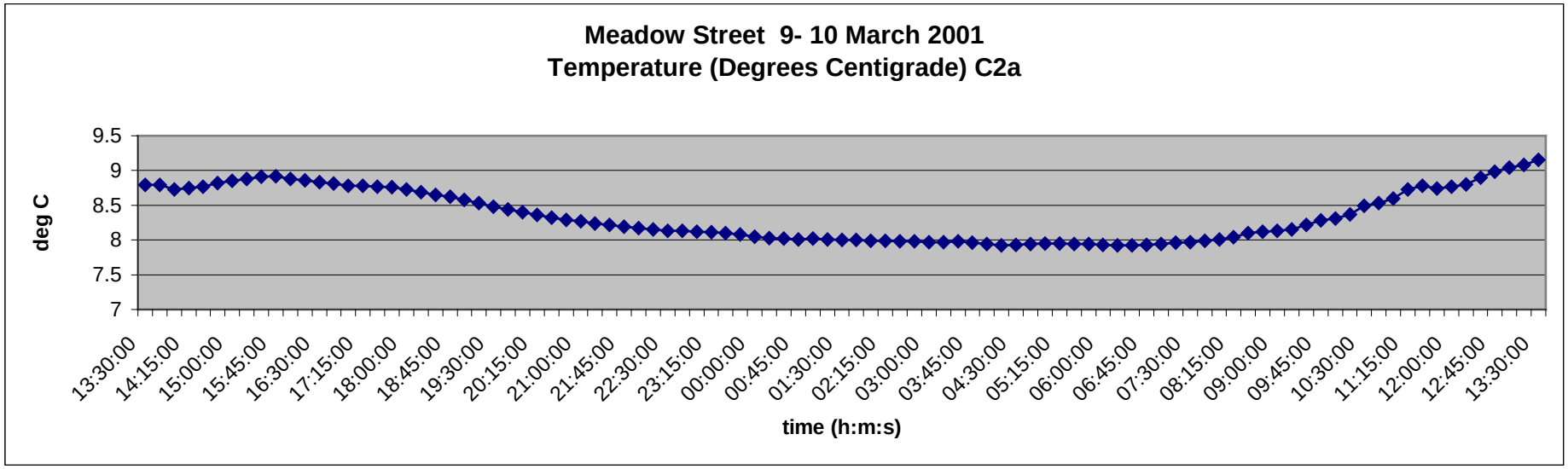

Humber Avenue 9- 10 March 2001
Continuous Monitor pH (pH units) C2a
pH units
8.1
8
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)


Meadow Street 9- 10 March 2001
Continuous Monitor pH (pH units) C2a
pH units
7.85
7.8
7.75
7.7
7.65
7.6
7.55
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)


Humber Avenue 9- 10 March 2001
Total Dissolved Solids (gl-1) C2a
gl-1
0.6
0.5
0.4
0.3
0.2
0.1
0
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

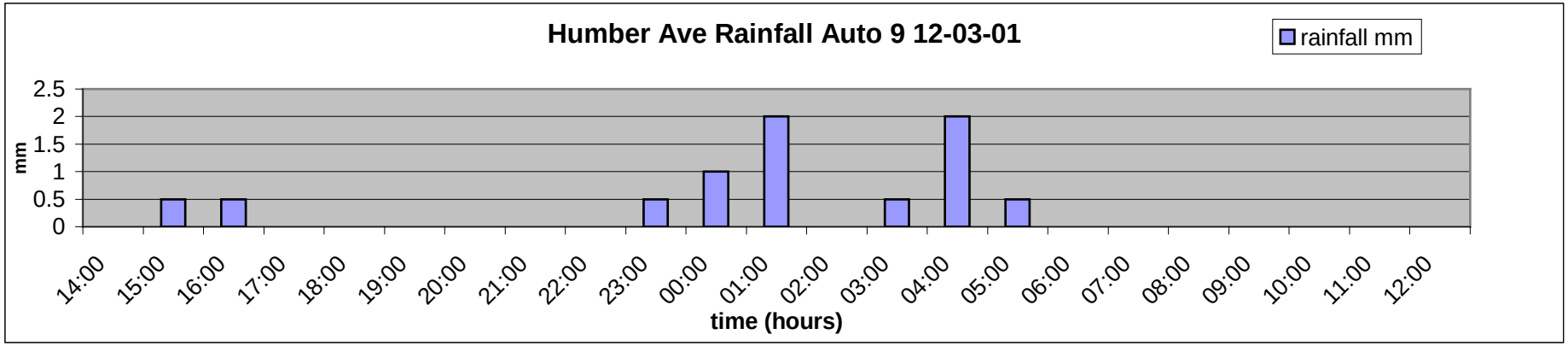

Meadow Street 9- 10 March 2001
Total Dissolved Solids (gl-1) C2a
gl-1
0.6
0.5
0.4
0.3
0.2
0.1
0
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)


Humber Avenue 9- 10 March 2001
Temperature (Degrees Centigrade) C2a
deg C
9
8.8
8.6
8.4
8.2
8
7.8
7.6
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)


Meadow Street 9- 10 March 2001
Temperature (Degrees Centigrade) C2a
deg C
9.5
9
8.5
8
7.5
7
13:30:00
14:15:00
15:00:00
15:45:00
16:30:00
17:15:00
18:00:00
18:45:00
19:30:00
20:15:00
21:00:00
21:45:00
22:30:00
23:15:00
00:00:00
00:45:00
01:30:00
02:15:00
03:00:00
03:45:00
04:30:00
05:15:00
06:00:00
06:45:00
07:30:00
08:15:00
09:00:00
09:45:00
10:30:00
11:15:00
12:00:00
12:45:00
13:30:00
time (h:m:s)

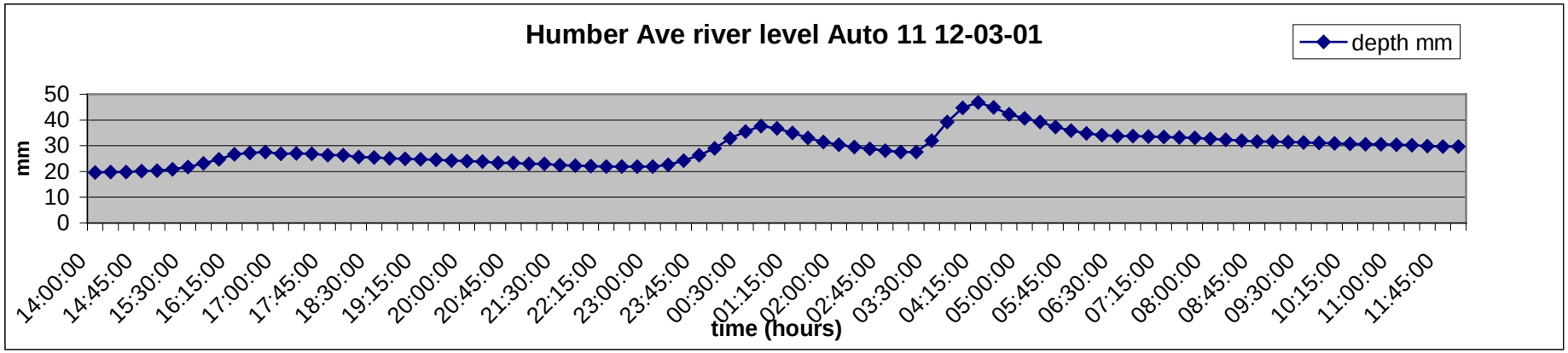
Auto 9 Humber Avenue 12-13 March 2001

a) Rainfall

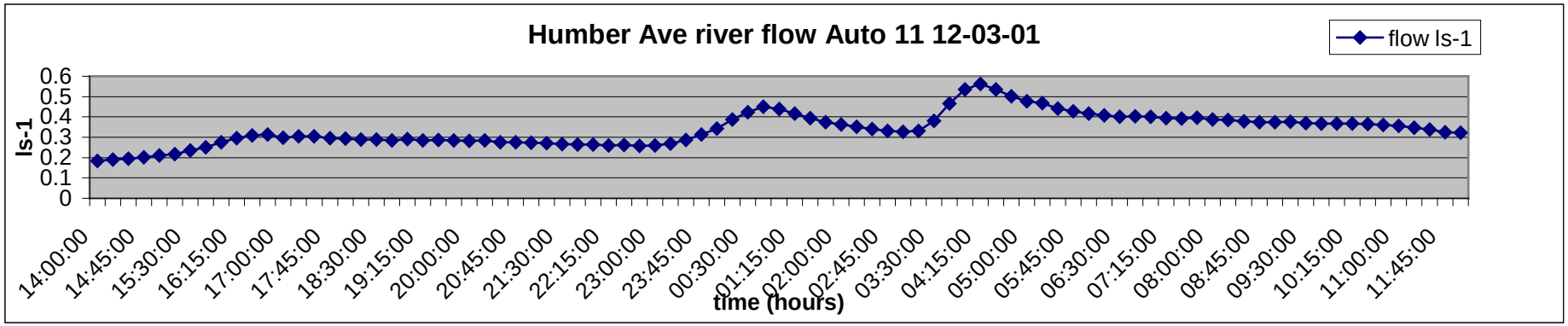


Dry	Rainfall	Dry Period	Initial storm		Second storm	Post storm period

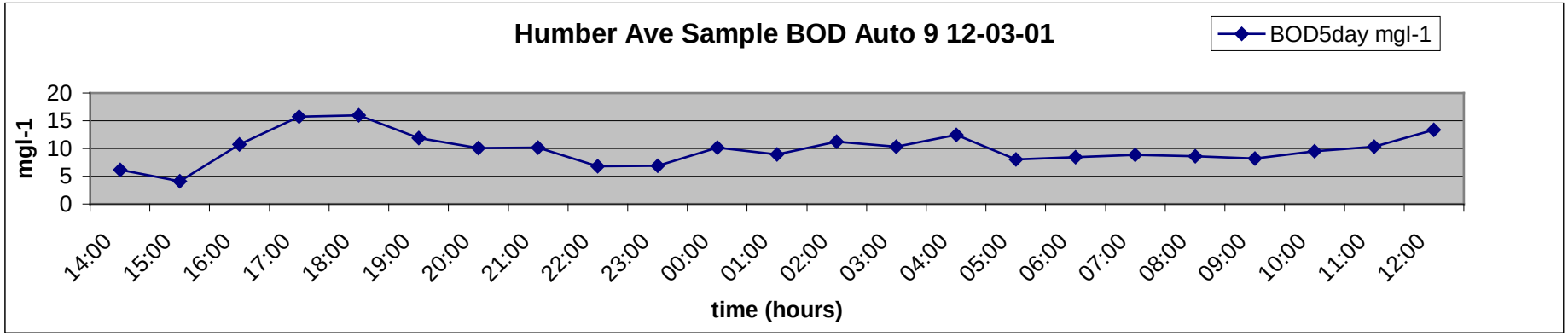
ai) River Level



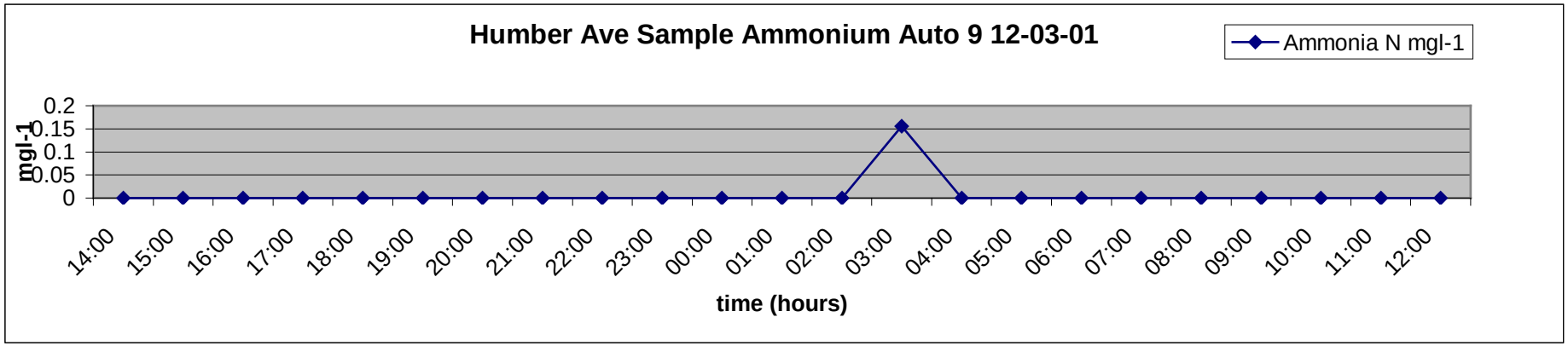
aii) River Flow



b) Biochemical Oxygen Demand (BOD)

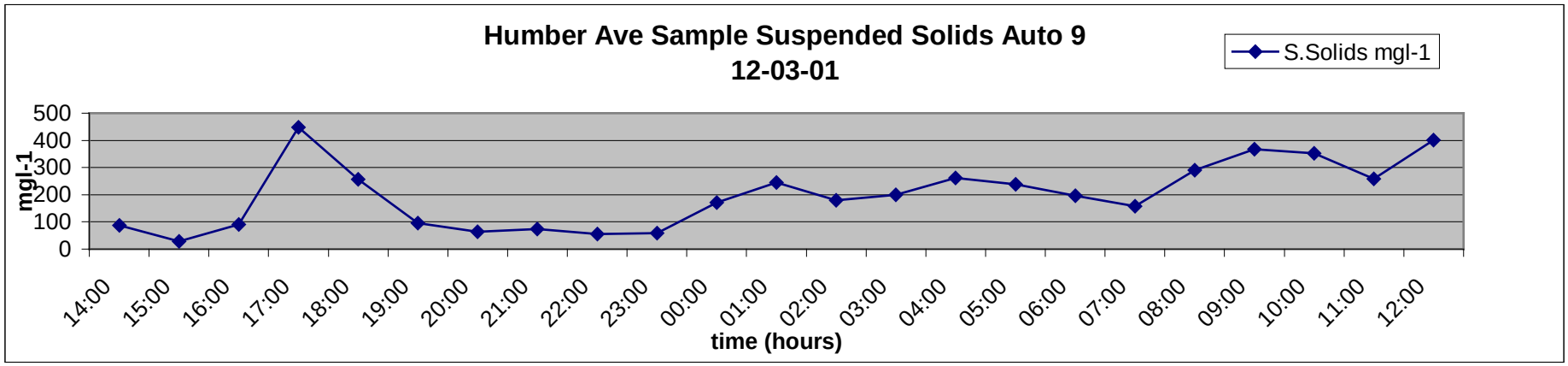


c) Ammonia

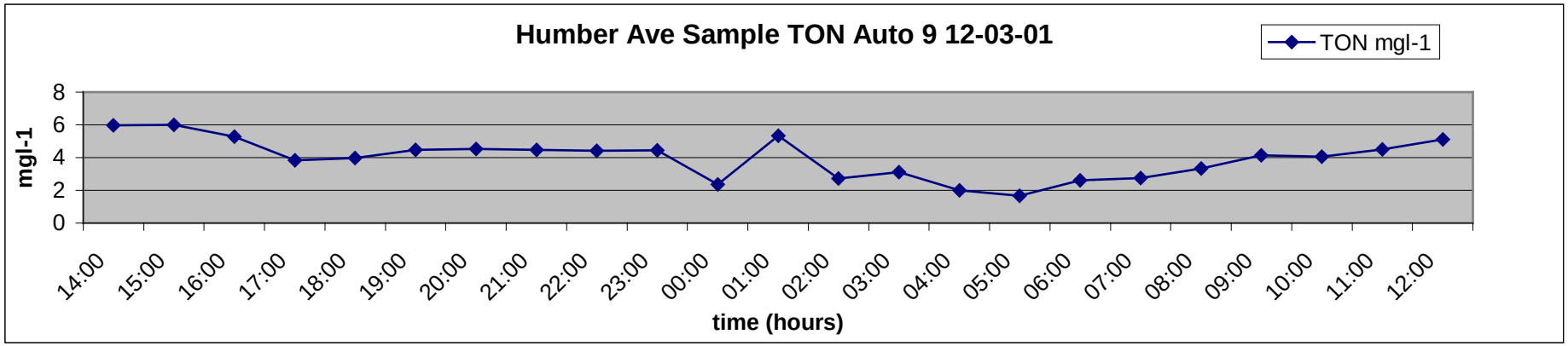


Dry	Rainfall	Dry Period	Initial storm		Second storm	Post storm period

d) Suspended Solids

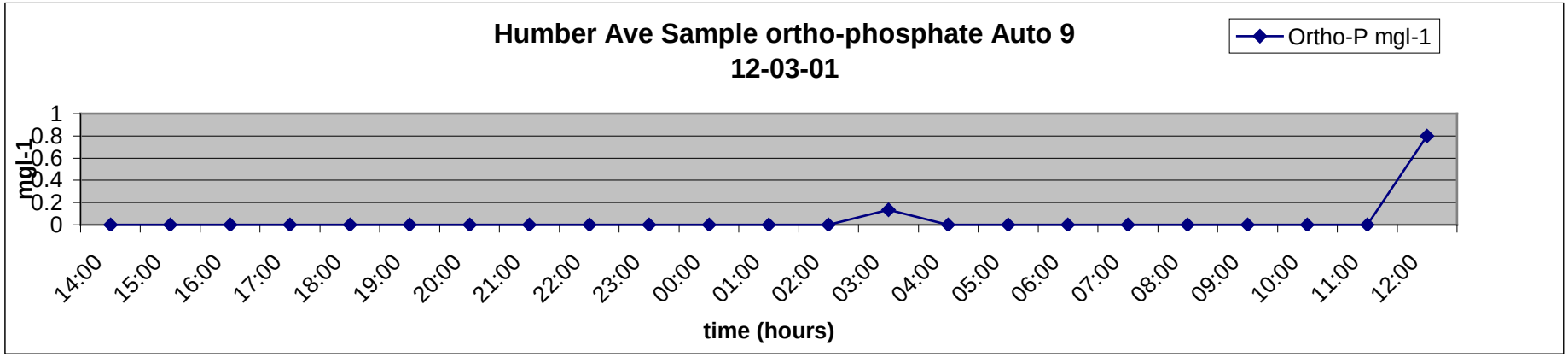


e) Total Oxidised Nitrogen (TON)

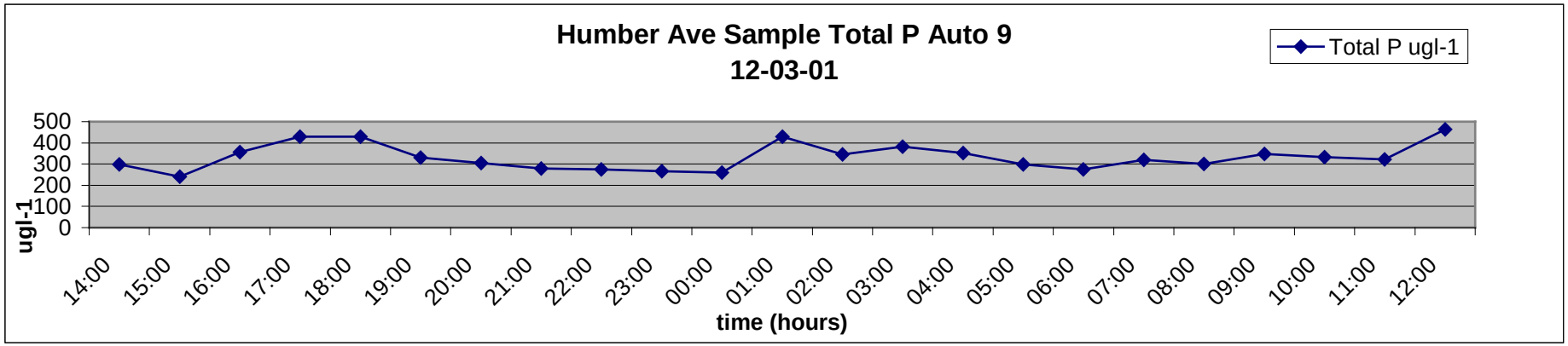


Dry	Rainfall	Dry Period	Initial storm		Second storm	Post storm period

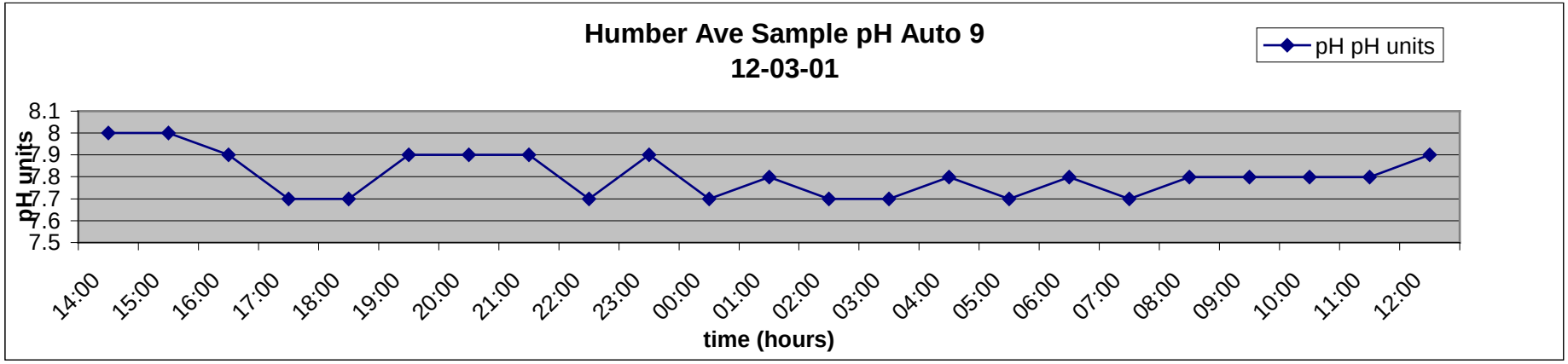
f) Ortho-phosphate



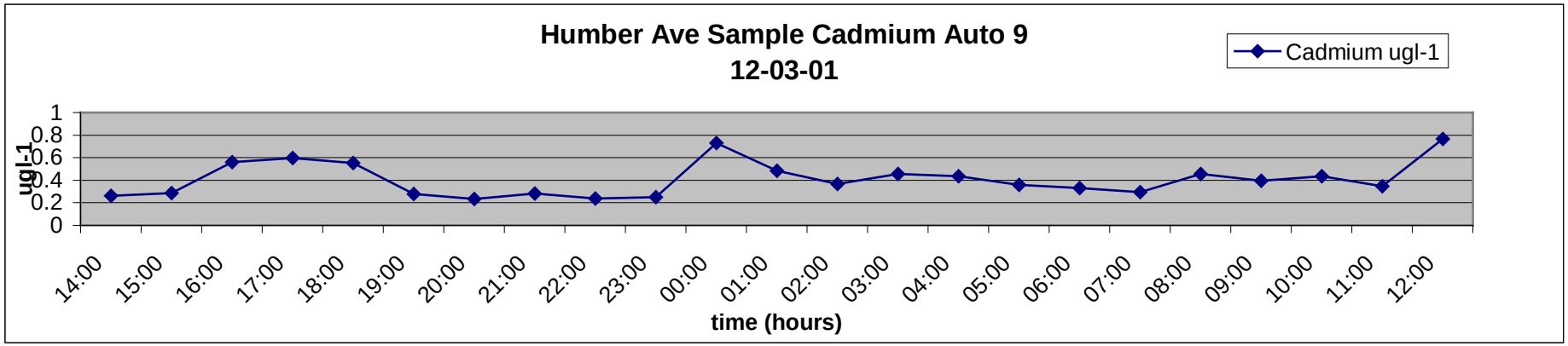
g) Total phosphate



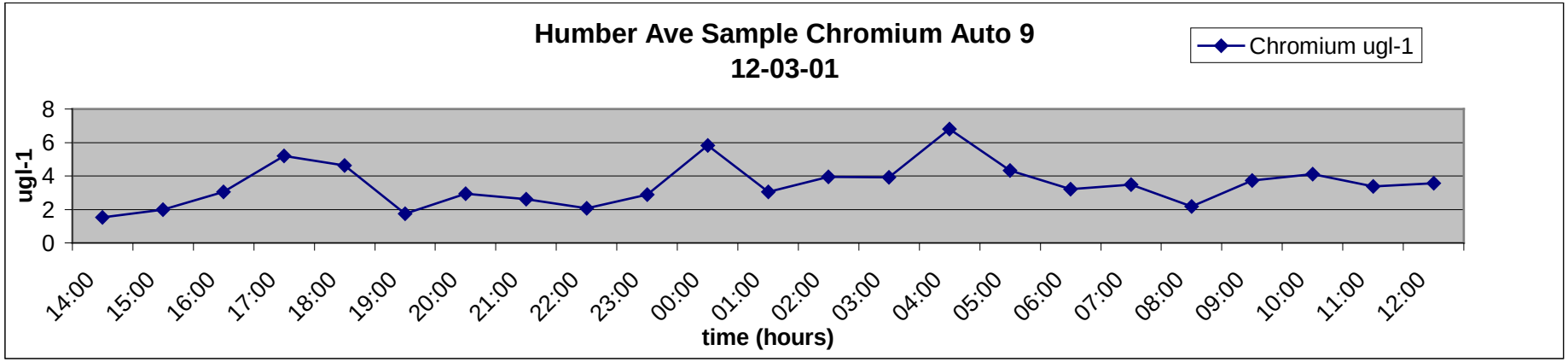
h) pH



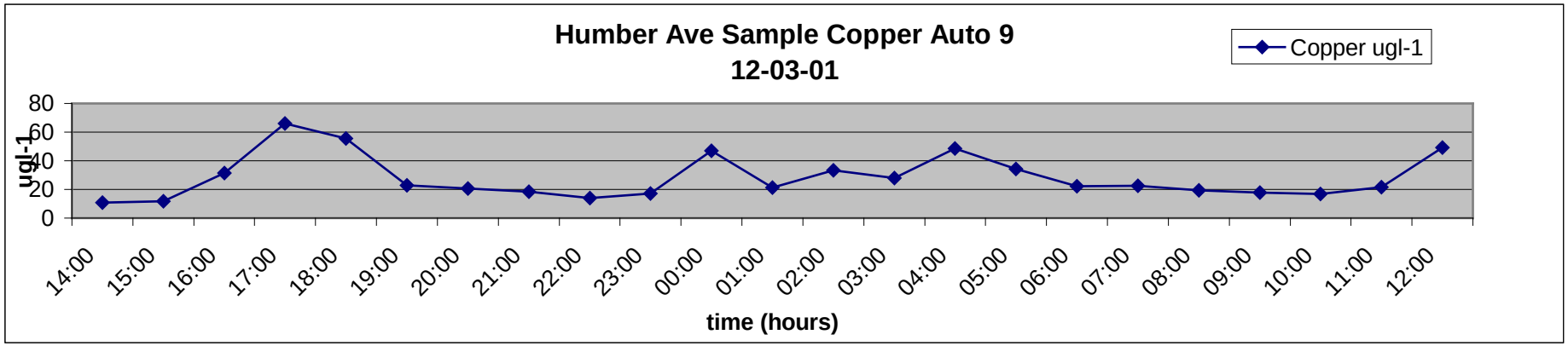
i) Cadmium



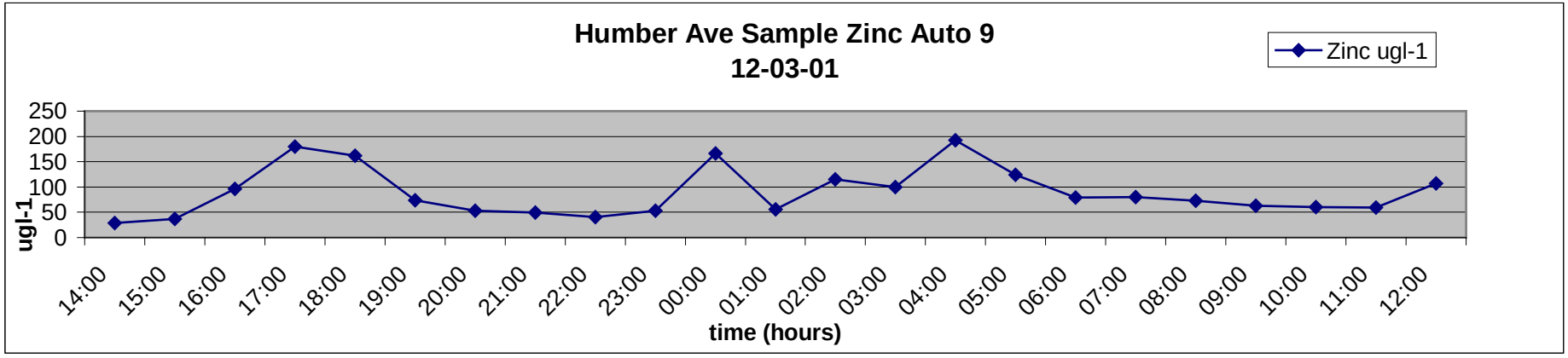
j) Chromium



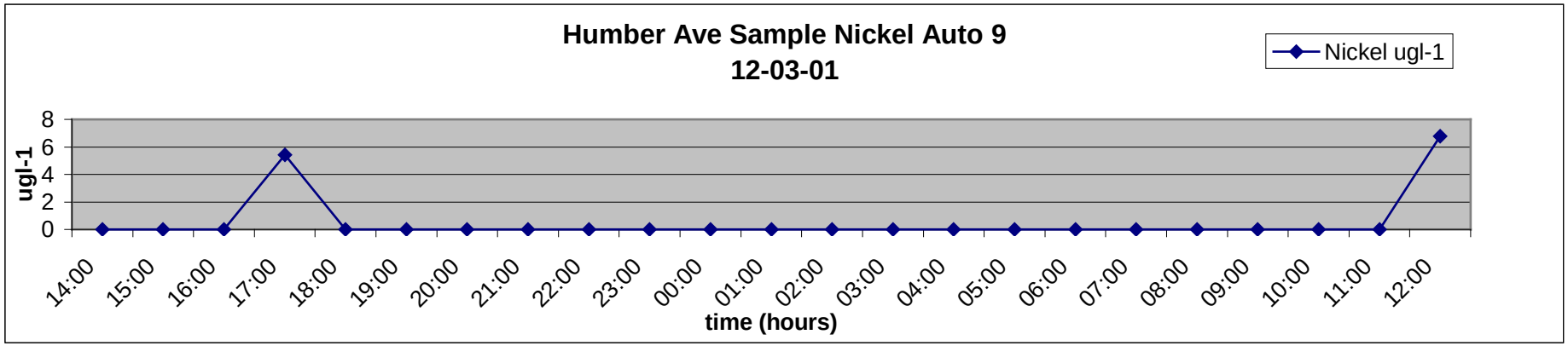
k) Copper



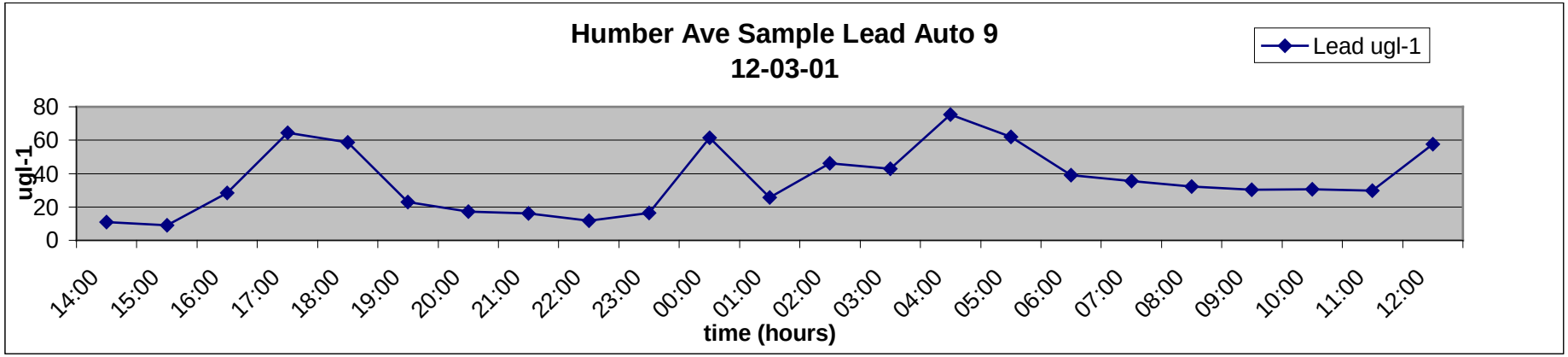
l) Zinc



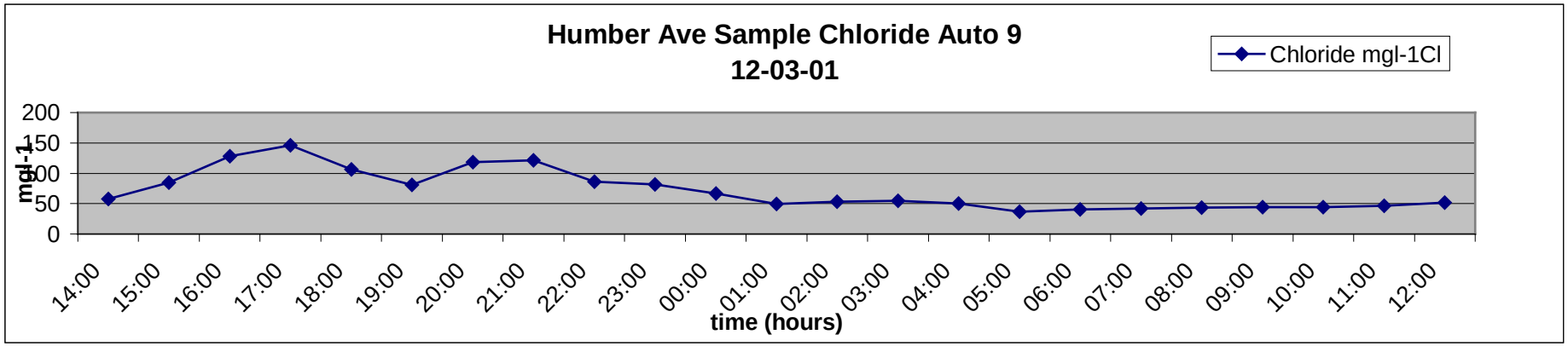
m) Nickel



n) Lead

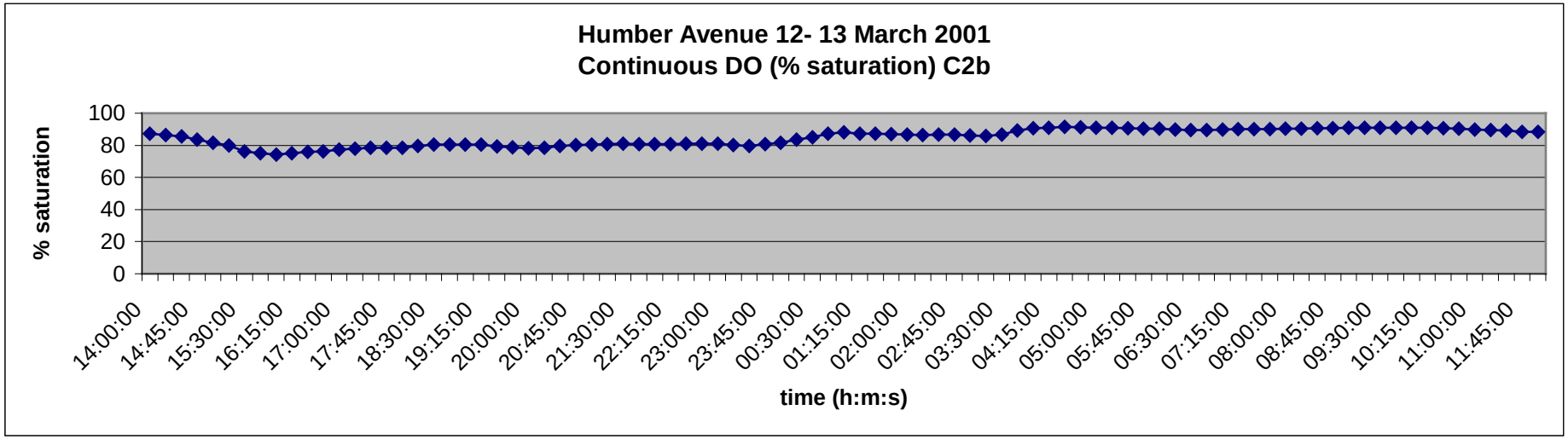


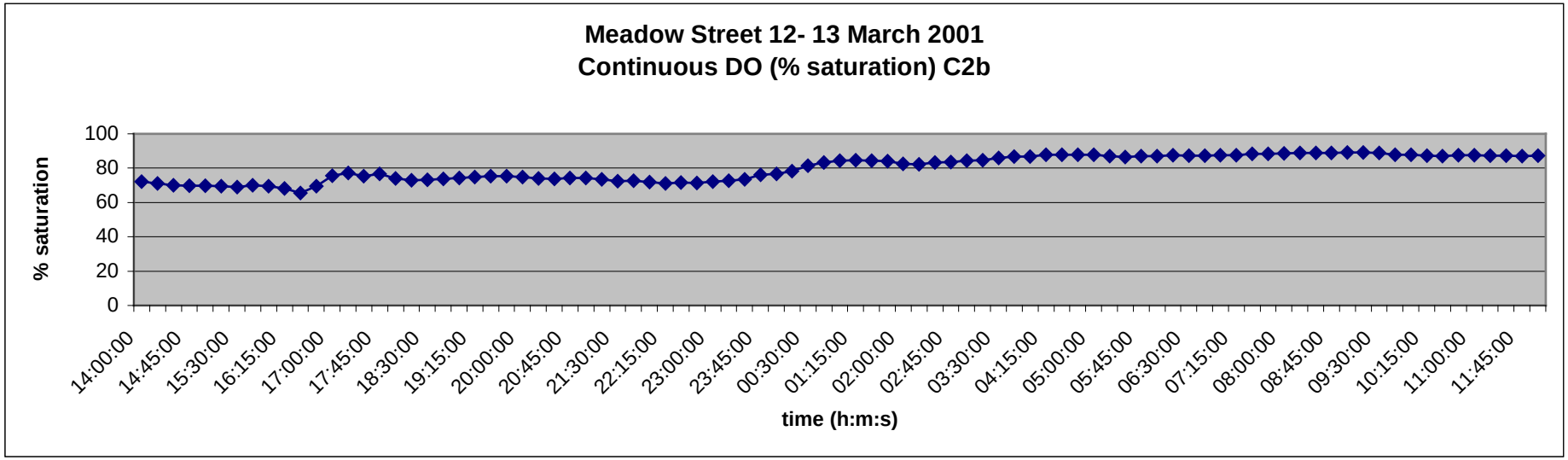
o) Chloride

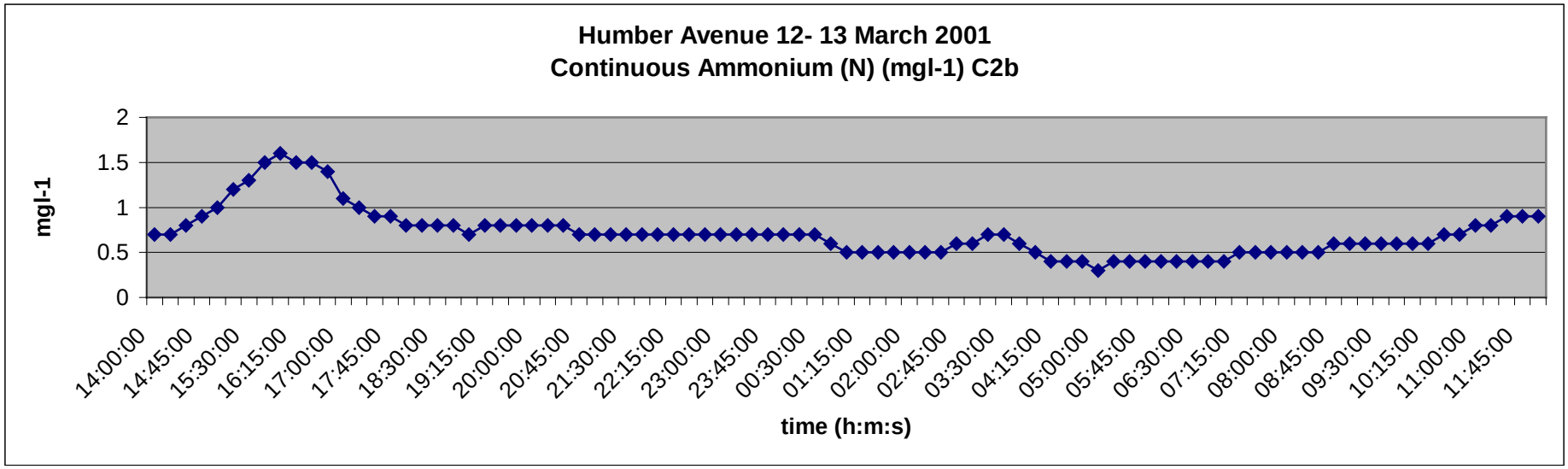


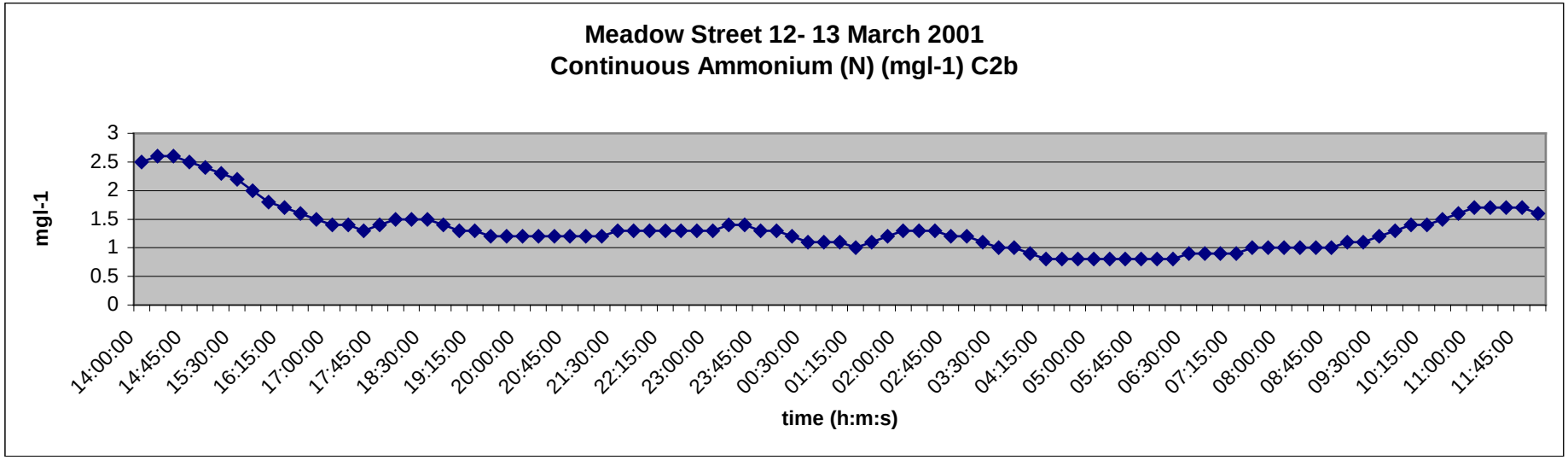
Dry	Rainfall	Dry Period	Initial storm		Second storm	Post storm period

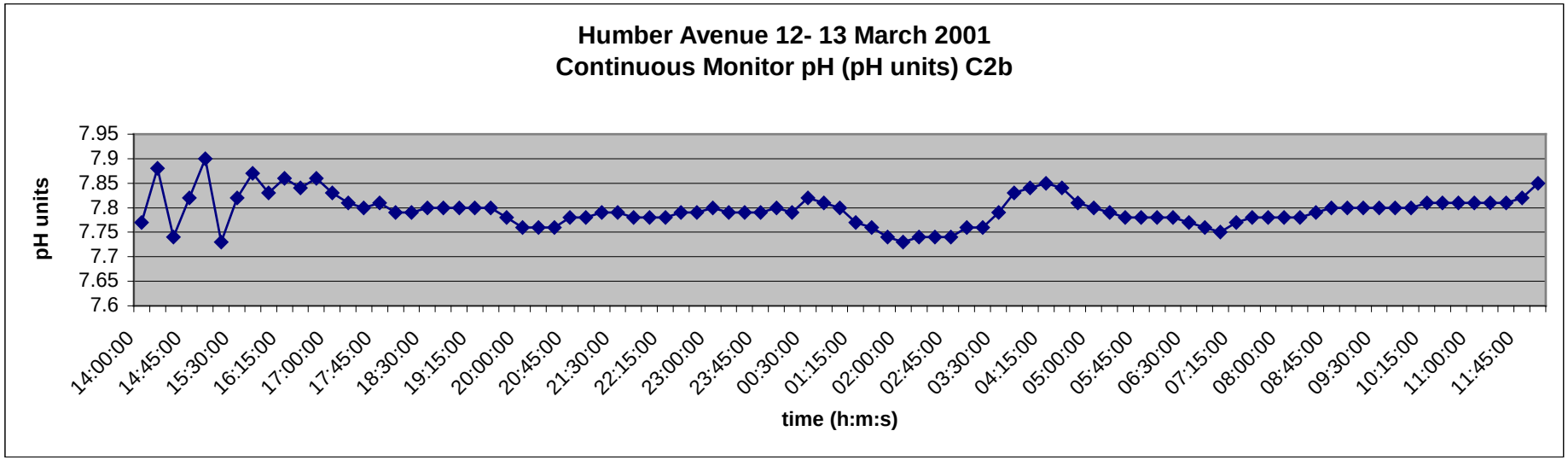
C2b Continuous monitor Results 12- 13 March 2001

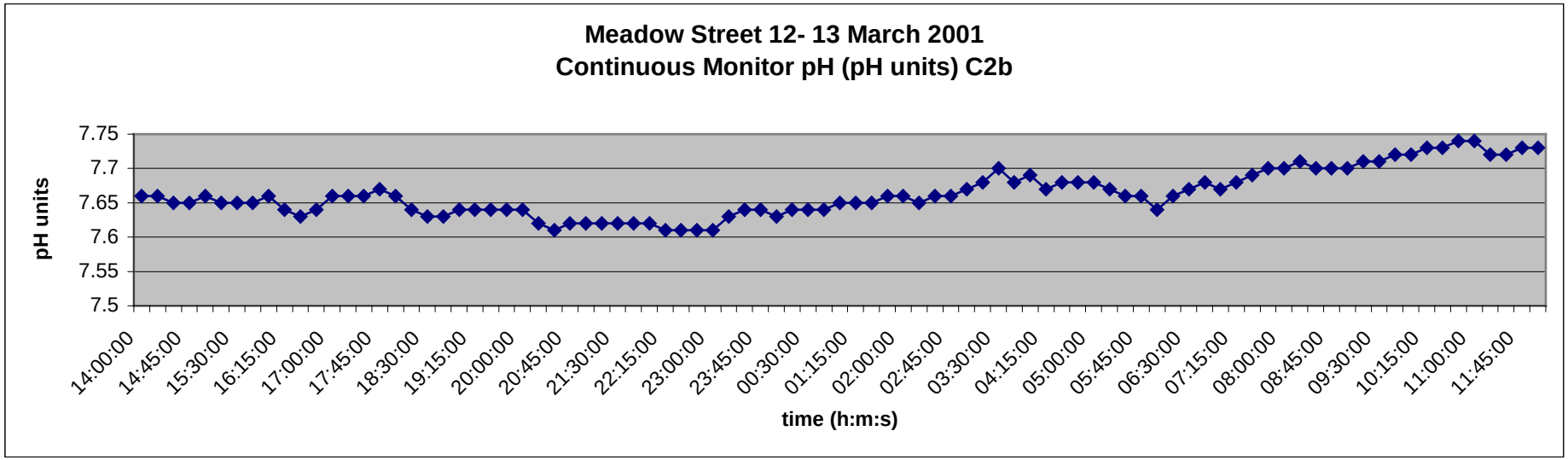


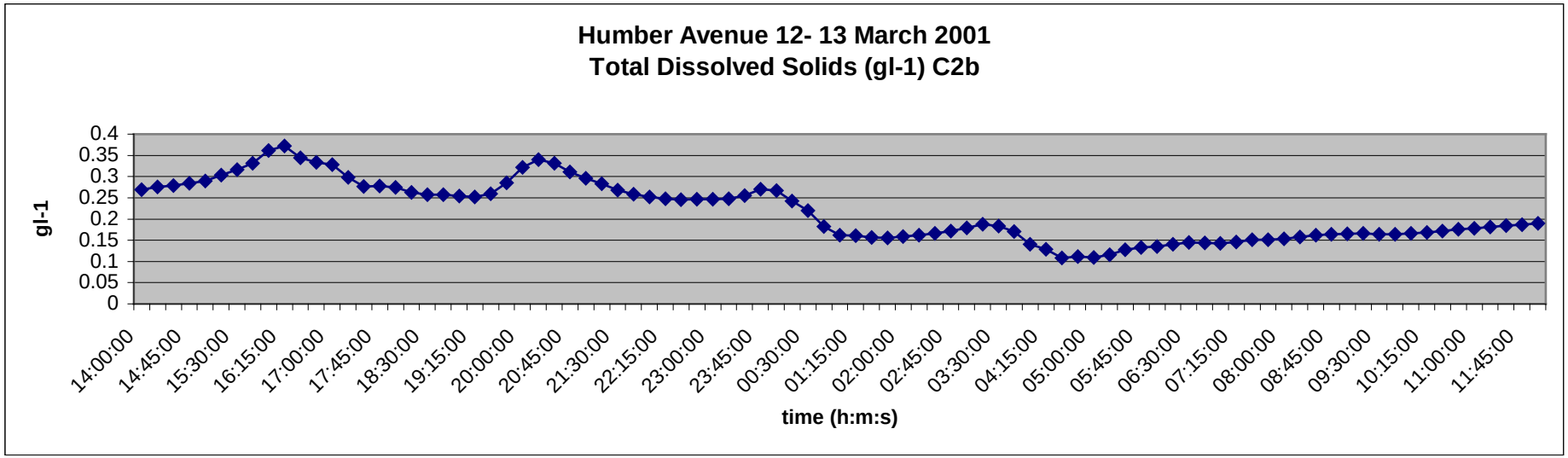


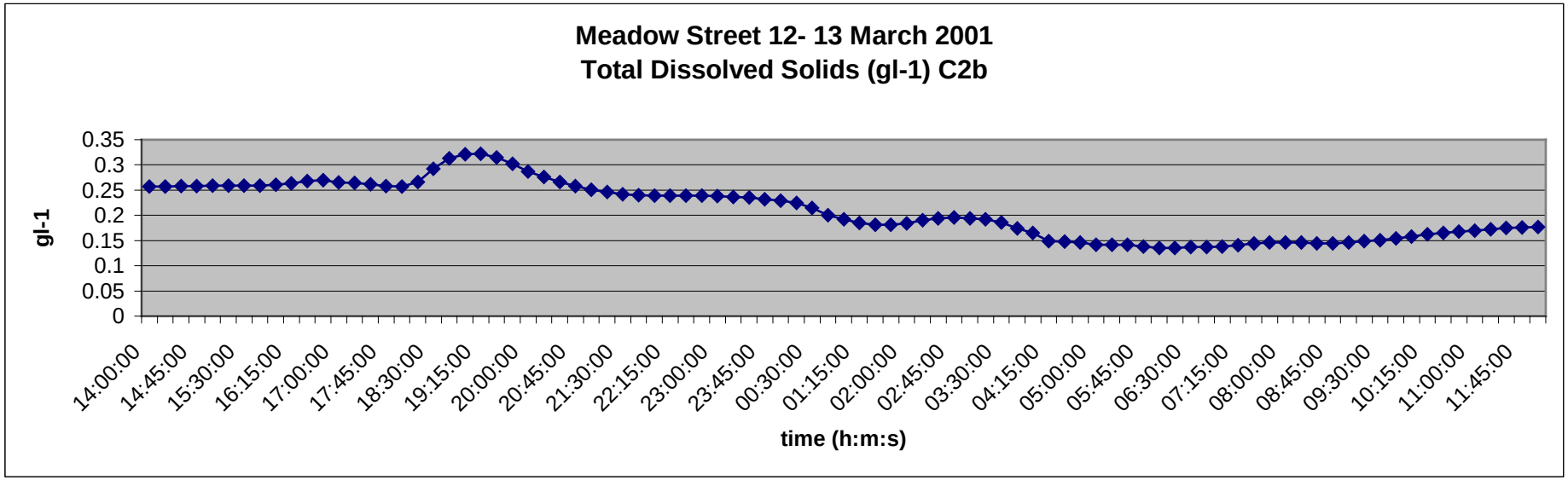

Humber Avenue 12- 13 March 2001
Continuous Ammonium (N) (mgl-1) C2b
mgl-1
2
1.5
1
0.5
0
14:00:00
14:45:00
15:30:00
16:15:00
17:00:00
17:45:00
18:30:00
19:15:00
20:00:00
20:45:00
21:30:00
22:15:00
23:00:00
23:45:00
00:30:00
01:15:00
02:00:00
02:45:00
03:30:00
04:15:00
05:00:00
05:45:00
06:30:00
07:15:00
08:00:00
08:45:00
09:30:00
10:15:00
11:00:00
11:45:00
time (h:m:s)


Meadow Street 12- 13 March 2001
Continuous Ammonium (N) (mgl-1) C2b
mgl-1
3
2.5
2
1.5
1
0.5
0
14:00:00
14:45:00
15:30:00
16:15:00
17:00:00
17:45:00
18:30:00
19:15:00
20:00:00
20:45:00
21:30:00
22:15:00
23:00:00
23:45:00
00:30:00
01:15:00
02:00:00
02:45:00
03:30:00
04:15:00
05:00:00
05:45:00
06:30:00
07:15:00
08:00:00
08:45:00
09:30:00
10:15:00
11:00:00
11:45:00
time (h:m:s)


Humber Avenue 12- 13 March 2001
Continuous Monitor pH (pH units) C2b
pH units
7.95
7.9
7.85
7.8
7.75
7.7
7.65
7.6
14:00:00
14:45:00
15:30:00
16:15:00
17:00:00
17:45:00
18:30:00
19:15:00
20:00:00
20:45:00
21:30:00
22:15:00
23:00:00
23:45:00
00:30:00
01:15:00
02:00:00
02:45:00
03:30:00
04:15:00
05:00:00
05:45:00
06:30:00
07:15:00
08:00:00
08:45:00
09:30:00
10:15:00
11:00:00
11:45:00
time (h:m:s)


Meadow Street 12- 13 March 2001
Continuous Monitor pH (pH units) C2b
pH units
7.75
7.7
7.65
7.6
7.55
7.5
14:00:00
14:45:00
15:30:00
16:15:00
17:00:00
17:45:00
18:30:00
19:15:00
20:00:00
20:45:00
21:30:00
22:15:00
23:00:00
23:45:00
00:30:00
01:15:00
02:00:00
02:45:00
03:30:00
04:15:00
05:00:00
05:45:00
06:30:00
07:15:00
08:00:00
08:45:00
09:30:00
10:15:00
11:00:00
11:45:00
time (h:m:s)


Humber Avenue 12- 13 March 2001
Total Dissolved Solids (gl-1) C2b
gl-1
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
14:00:00
14:45:00
15:30:00
16:15:00
17:00:00
17:45:00
18:30:00
19:15:00
20:00:00
20:45:00
21:30:00
22:15:00
23:00:00
23:45:00
00:30:00
01:15:00
02:00:00
02:45:00
03:30:00
04:15:00
05:00:00
05:45:00
06:30:00
07:15:00
08:00:00
08:45:00
09:30:00
10:15:00
11:00:00
11:45:00
time (h:m:s)


Meadow Street 12- 13 March 2001
Total Dissolved Solids (gl-1) C2b
gl-1
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
14:00:00
14:45:00
15:30:00
16:15:00
17:00:00
17:45:00
18:30:00
19:15:00
20:00:00
20:45:00
21:30:00
22:15:00
23:00:00
23:45:00
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01:15:00
02:00:00
02:45:00
03:30:00
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05:45:00
06:30:00
07:15:00
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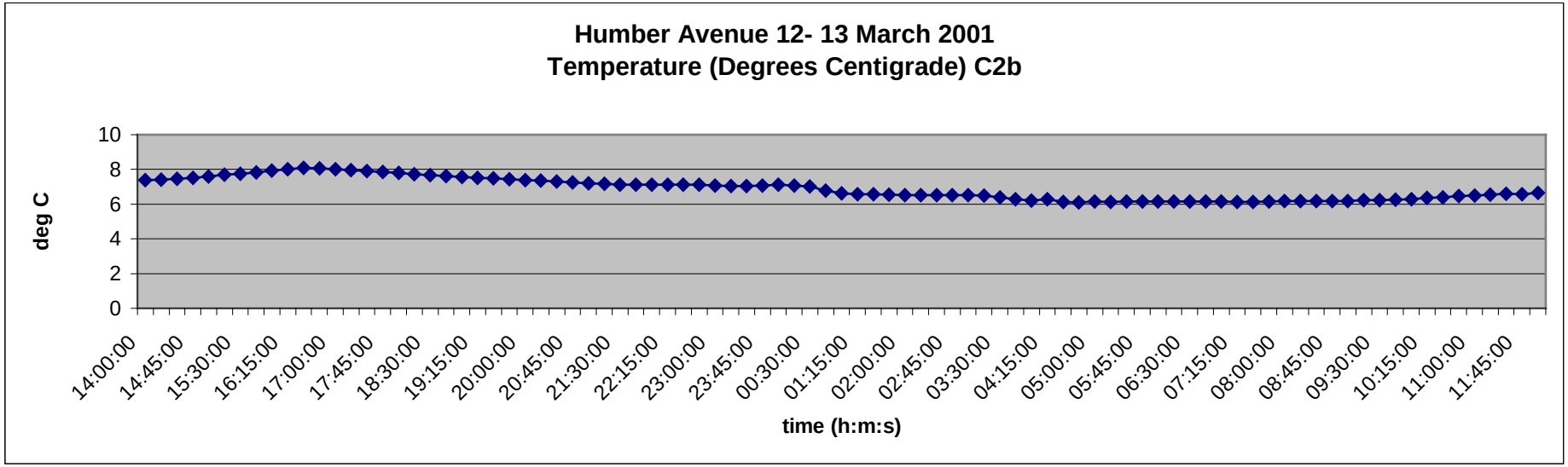
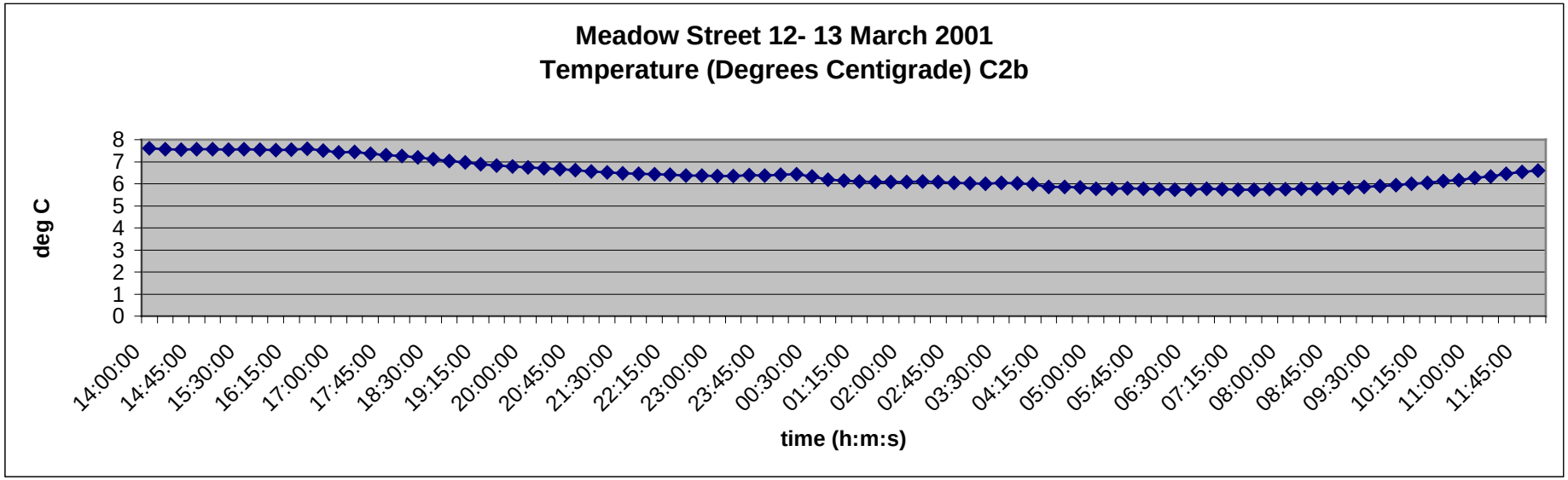
08:45:00
09:30:00
10:15:00
11:00:00
11:45:00
time (h:m:s)


Humber Avenue 12- 13 March 2001
Temperature (Degrees Centigrade) C2b
deg C
10
8
6
4
2
0
14:00:00
14:45:00
15:30:00
16:15:00
17:00:00
17:45:00
18:30:00
19:15:00
20:00:00
20:45:00
21:30:00
22:15:00
23:00:00
23:45:00
00:30:00
01:15:00
02:00:00
02:45:00
03:30:00
04:15:00
05:00:00
05:45:00
06:30:00
07:15:00
08:00:00
08:45:00
09:30:00
10:15:00
11:00:00
11:45:00
time (h:m:s)


Meadow Street 12- 13 March 2001
Temperature (Degrees Centigrade) C2b
deg C
8
7
6
5
4
3
2
1
0
14:00:00
14:45:00
15:30:00
16:15:00
17:00:00
17:45:00
18:30:00
19:15:00
20:00:00
20:45:00
21:30:00
22:15:00
23:00:00
23:45:00
00:30:00
01:15:00
02:00:00
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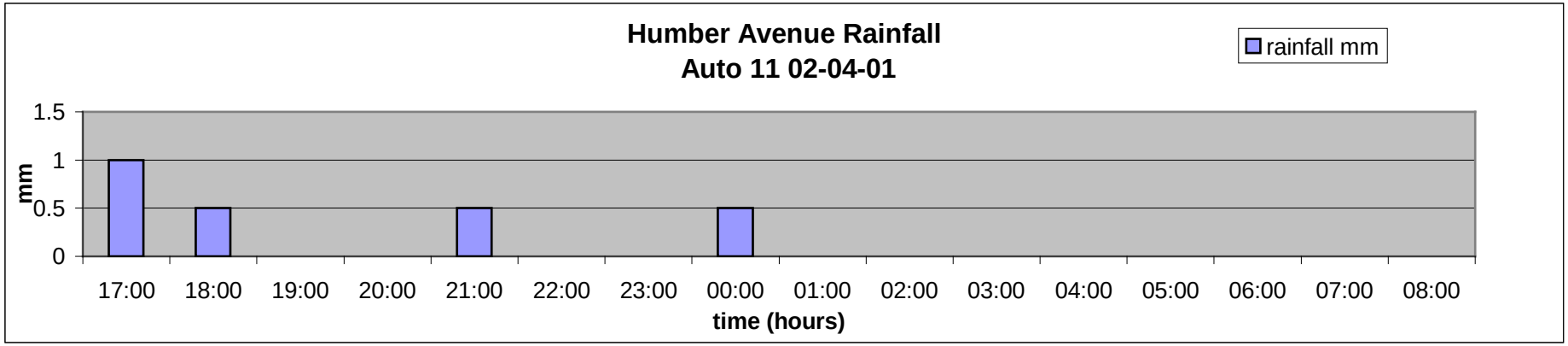
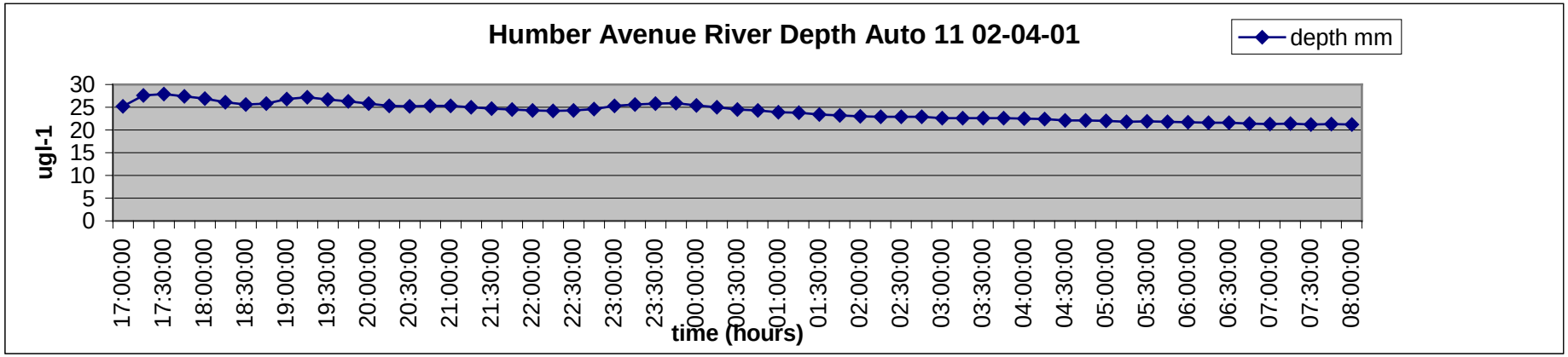
04:15:00
05:00:00
05:45:00
06:30:00
07:15:00
08:00:00
08:45:00
09:30:00
10:15:00
11:00:00
11:45:00
time (h:m:s)

Auto 11 Humber Avenue 2-3 April 2001

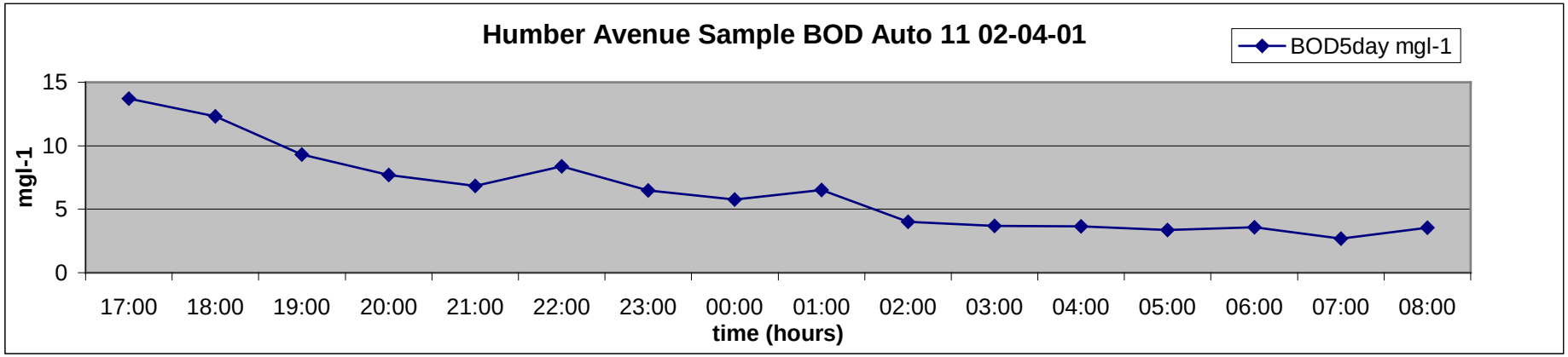
a) Rainfall



ai) River Depth

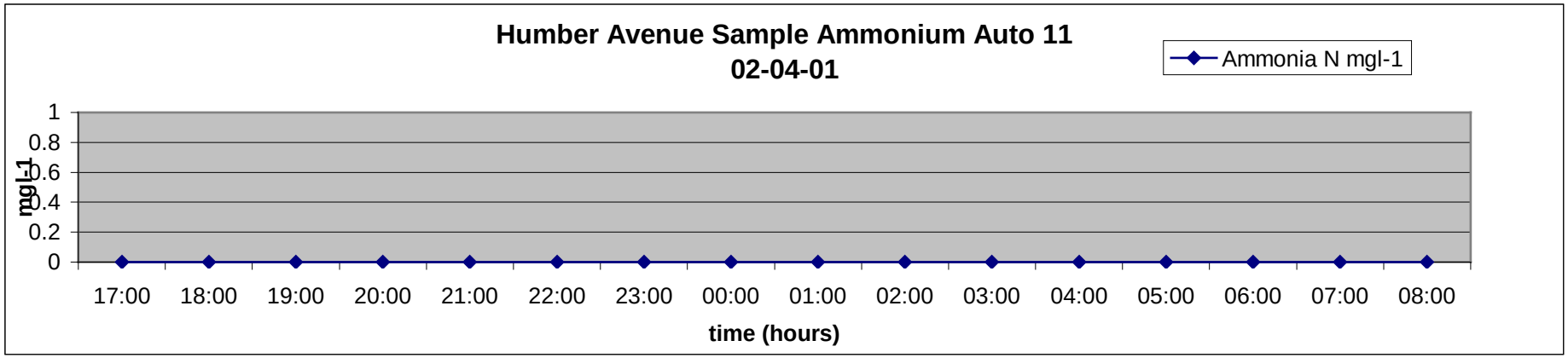


b) Biochemical Oxygen Demand

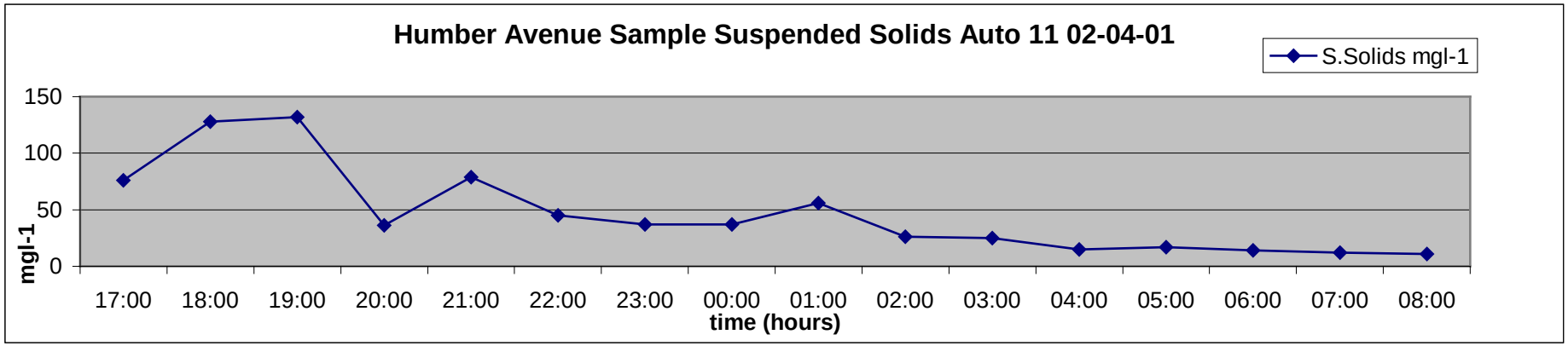


Rainfall	Post rain	rain		rain	Dry weather period

c) Ammonia

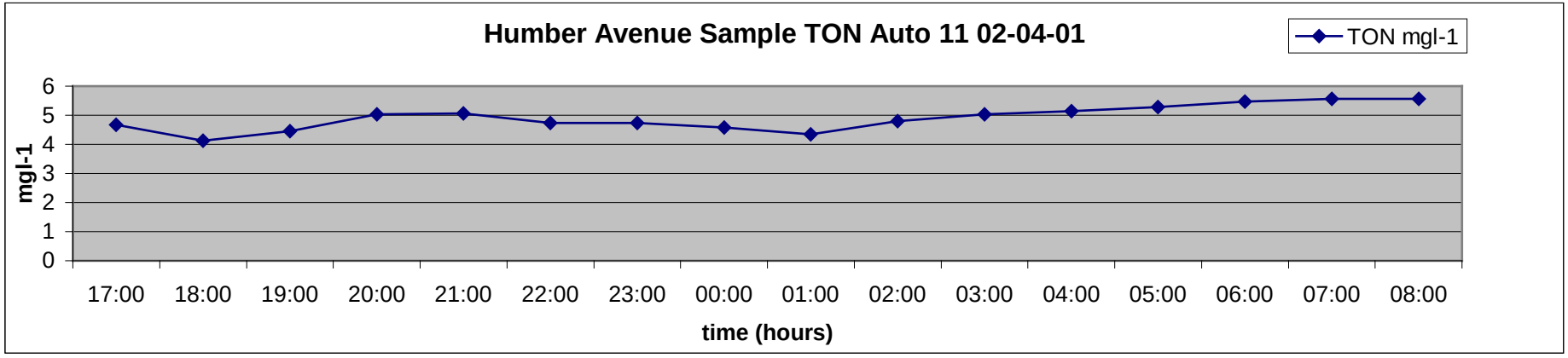


d) Suspended Solids

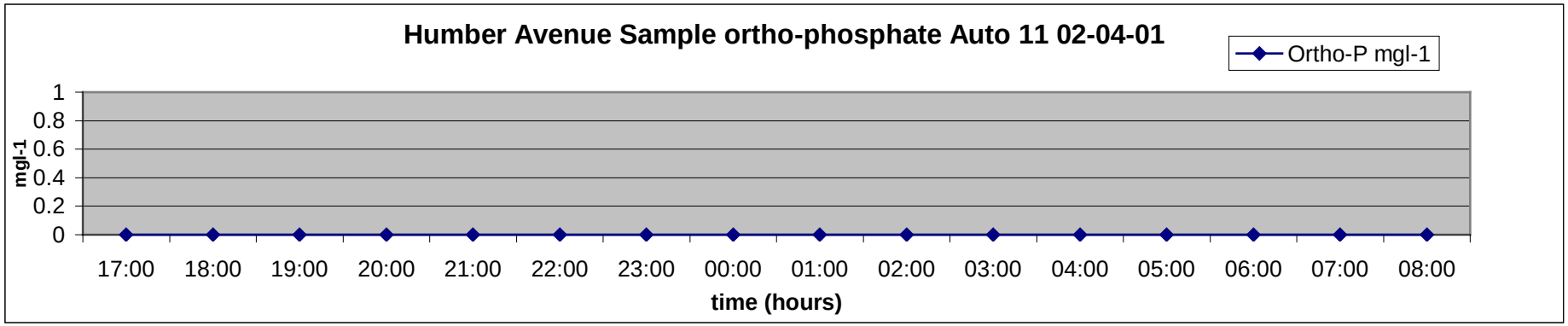


Rainfall	Post rain	rain		rain	Dry weather period

e) Total Oxidised Nitrogen

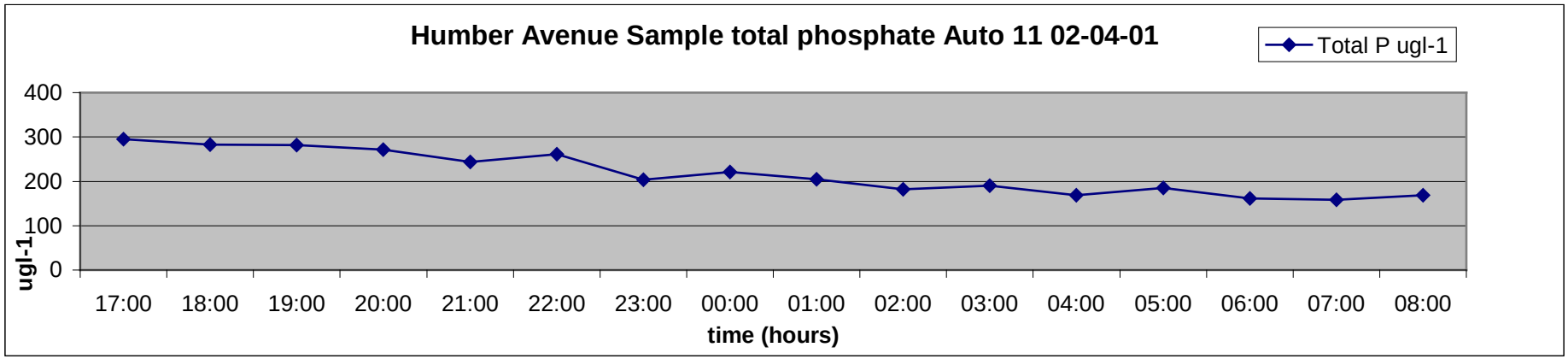


f) Ortho-phosphate

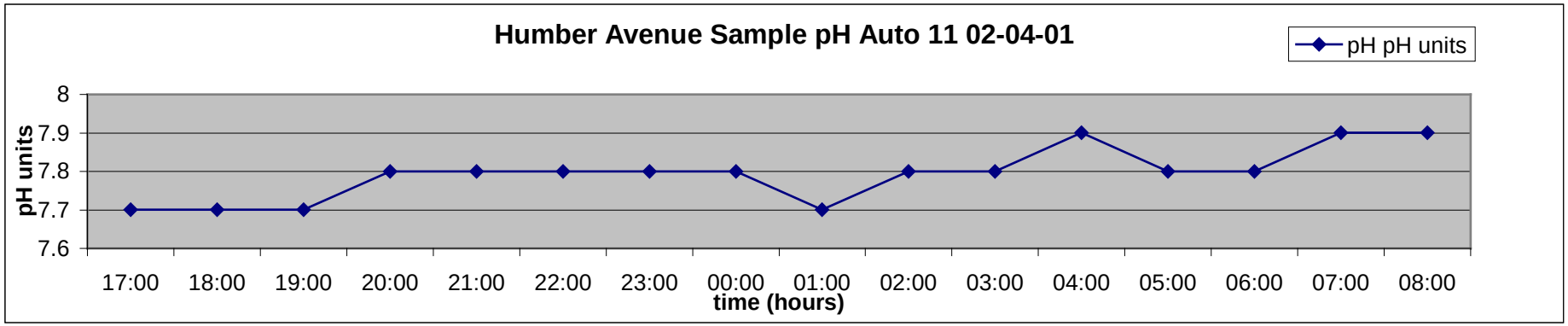


Rainfall	Post rain	rain		rain	Dry weather period

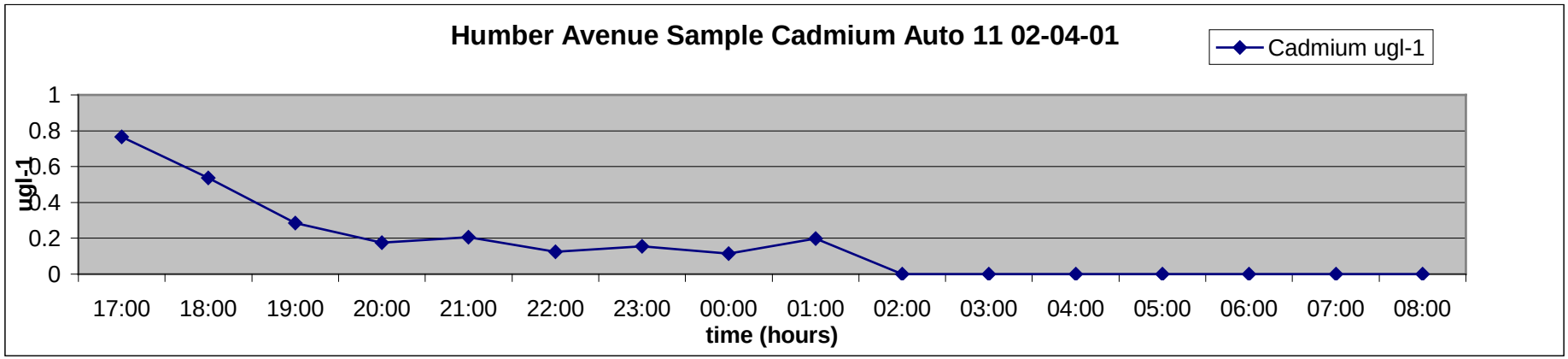
g) Total phosphate



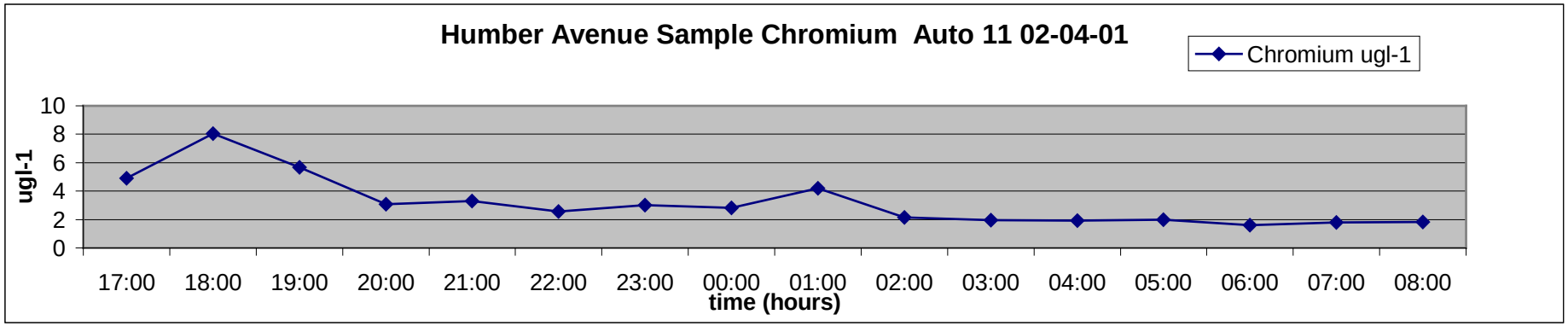
h) pH



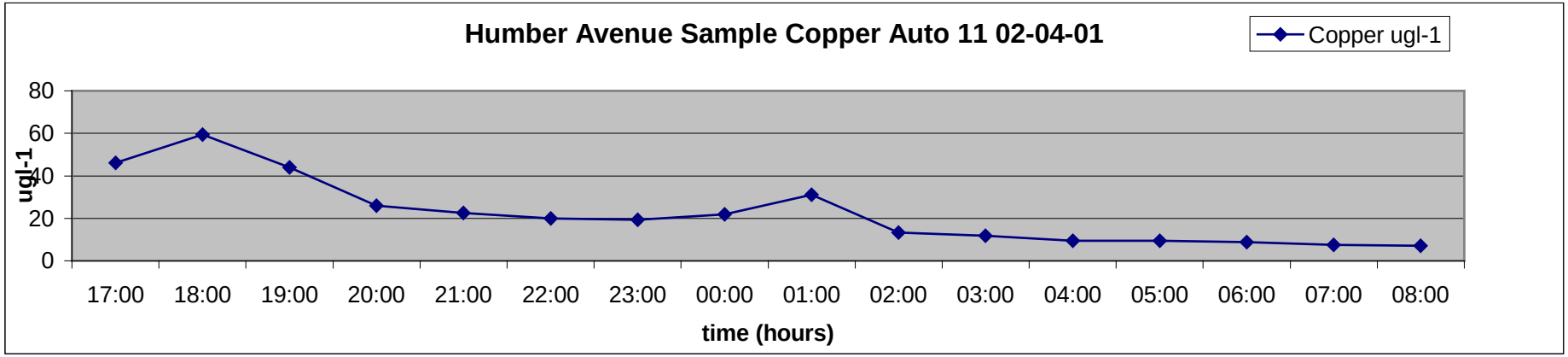
i) Cadmium



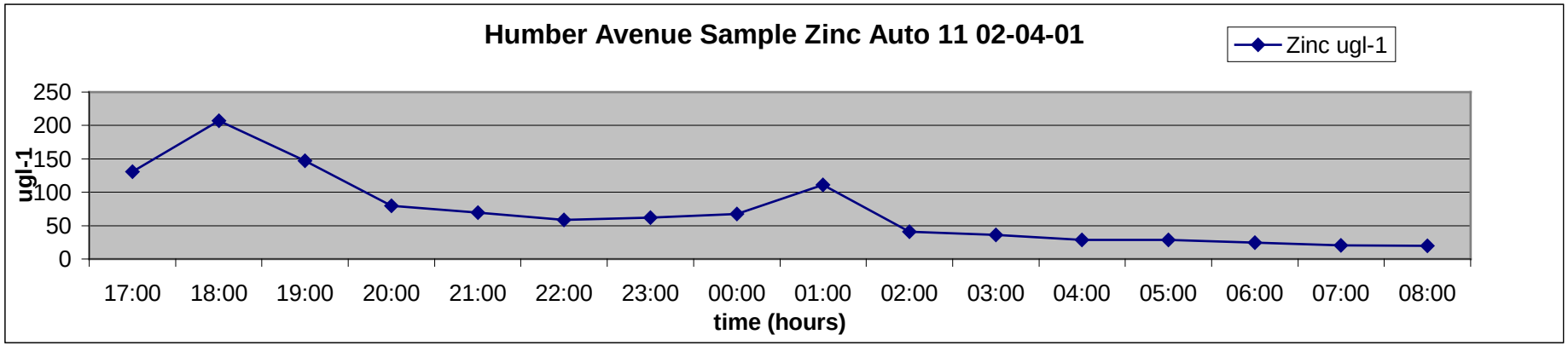
j) Chromium



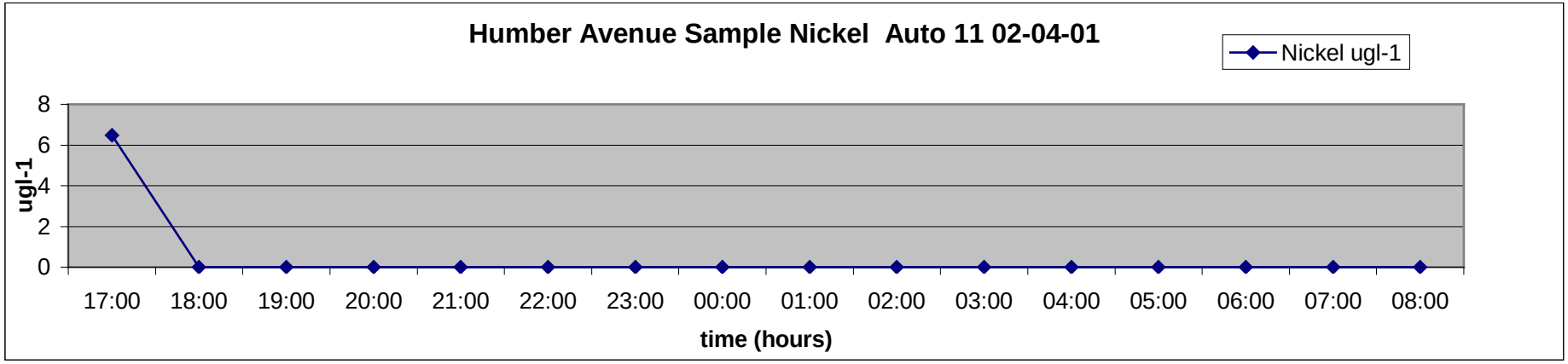
k) Copper



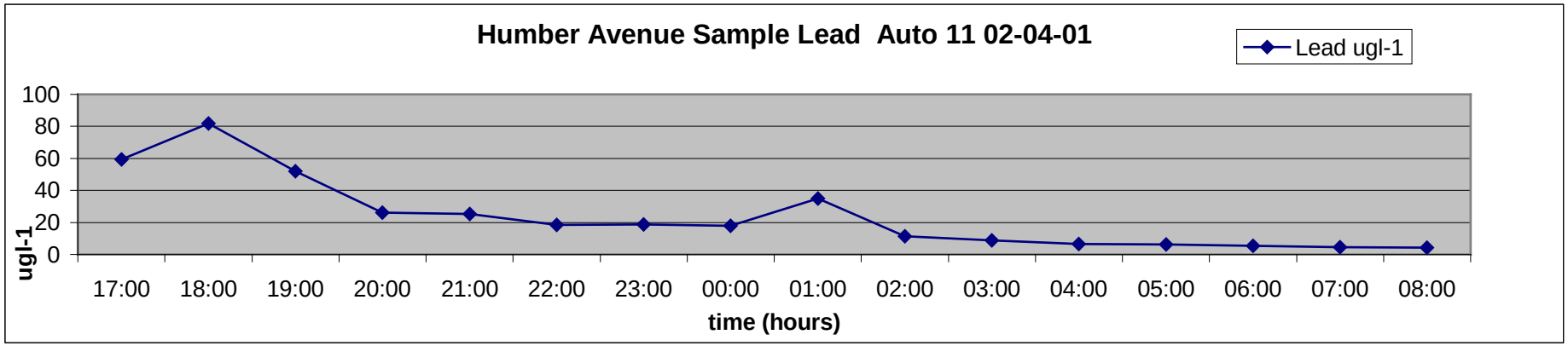
l) Zinc



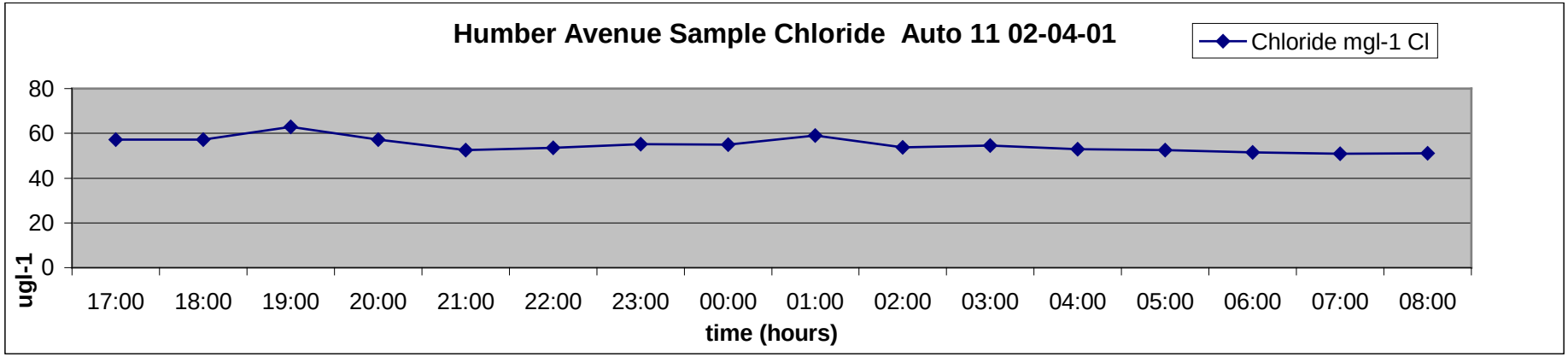
m) Nickel



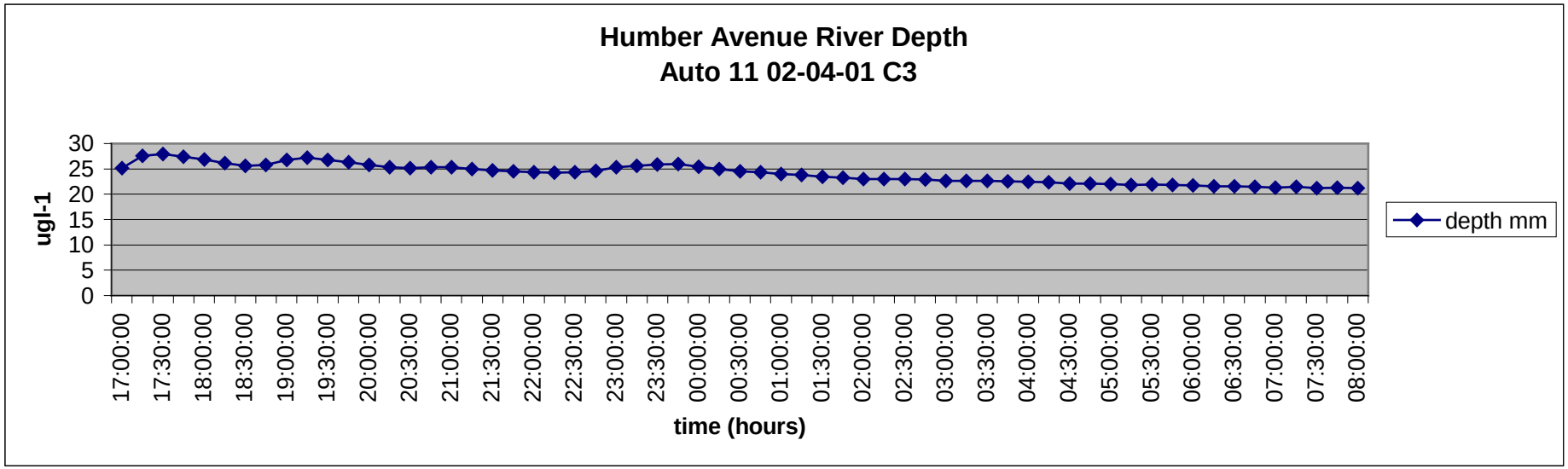
n) Lead

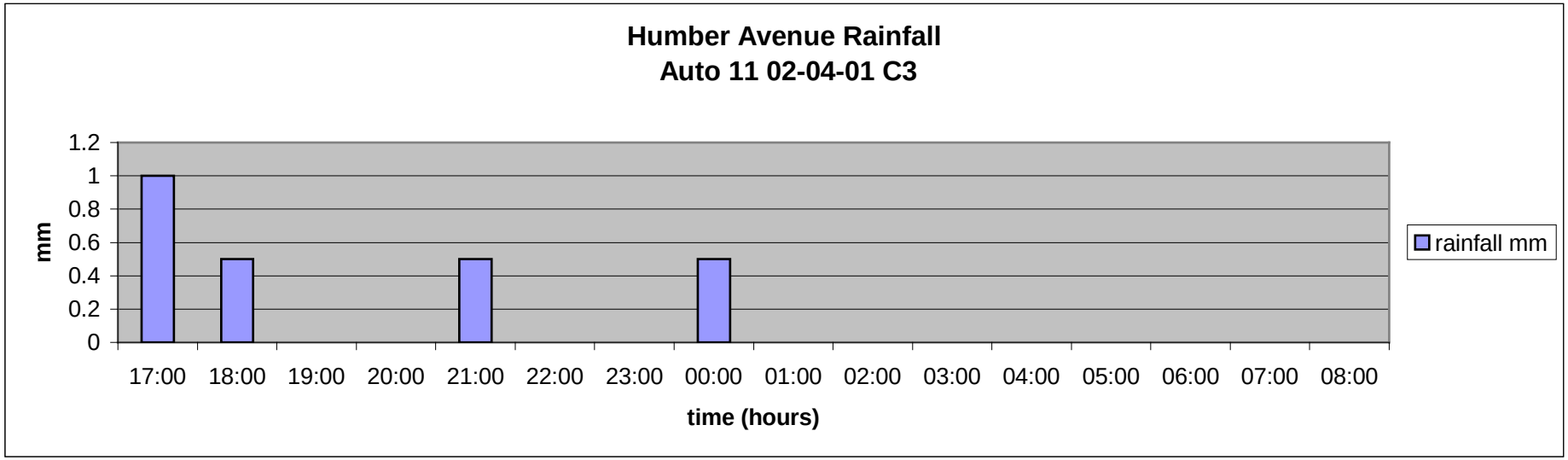


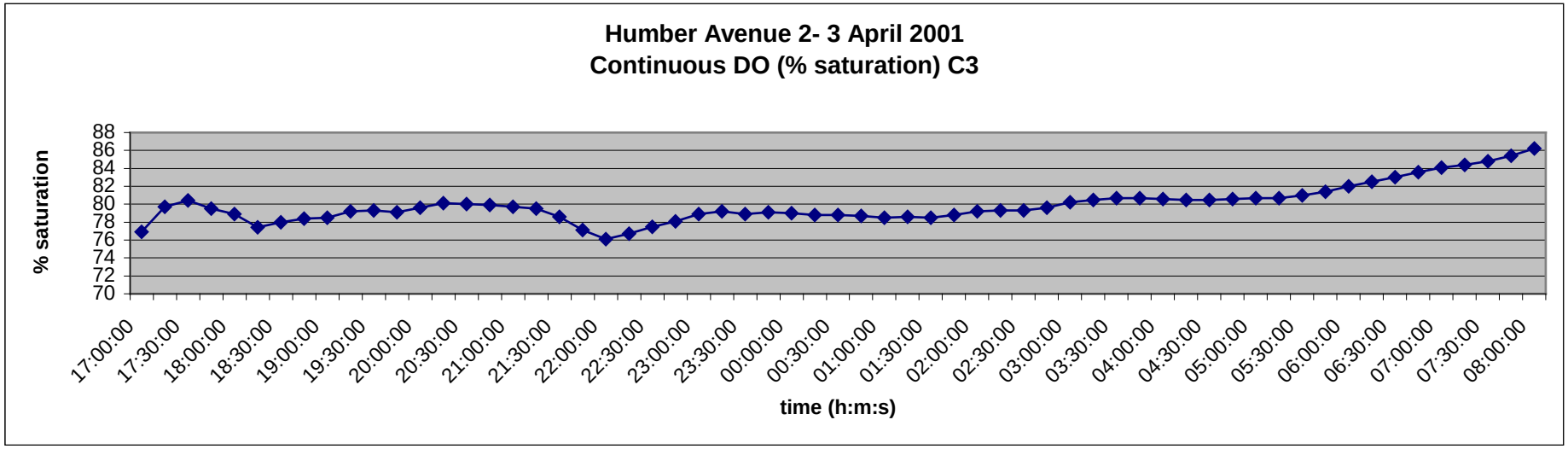
o) Chloride

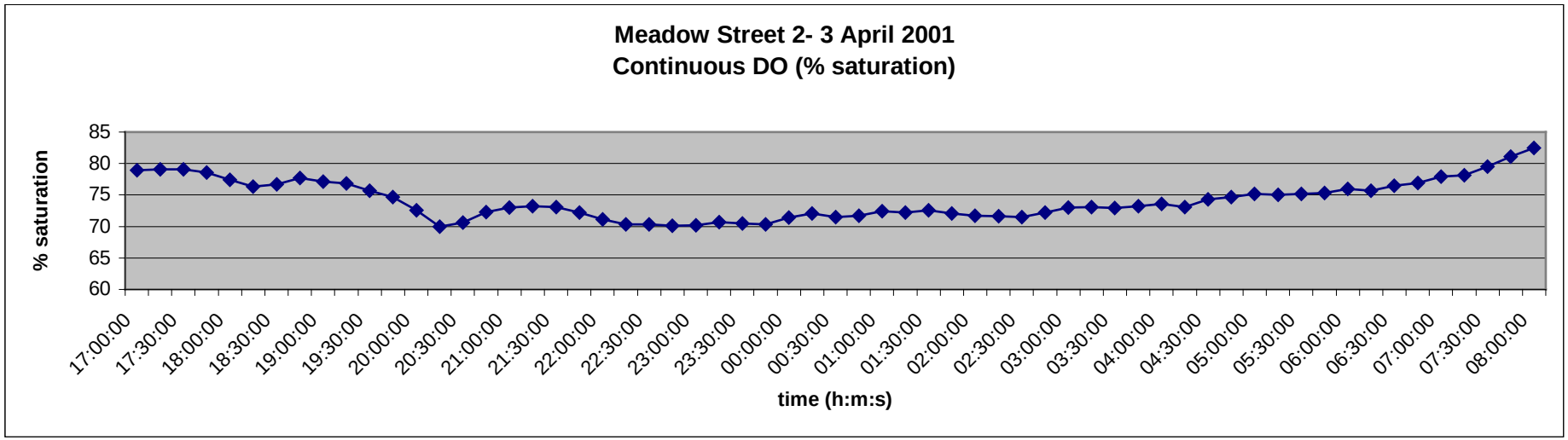


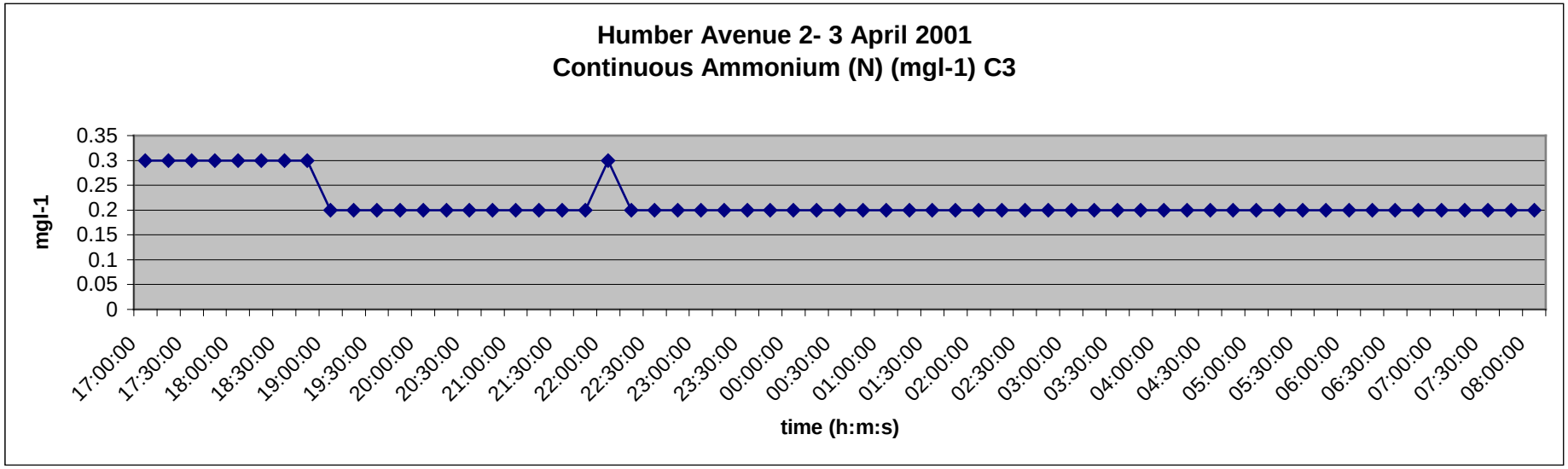
C3 Depth and Continuous monitors

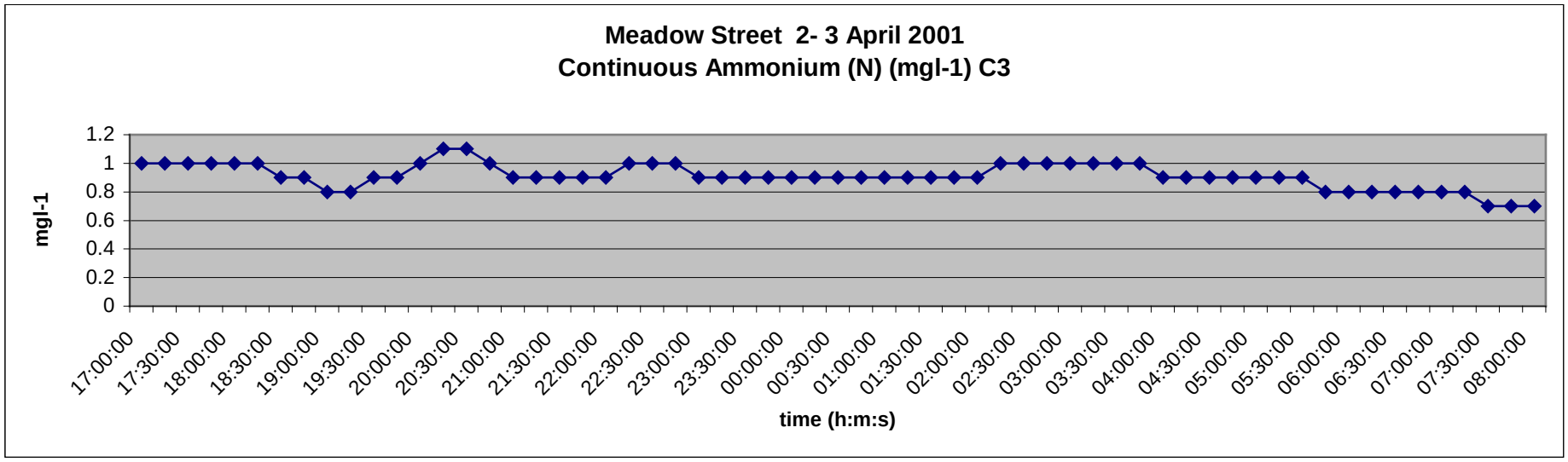


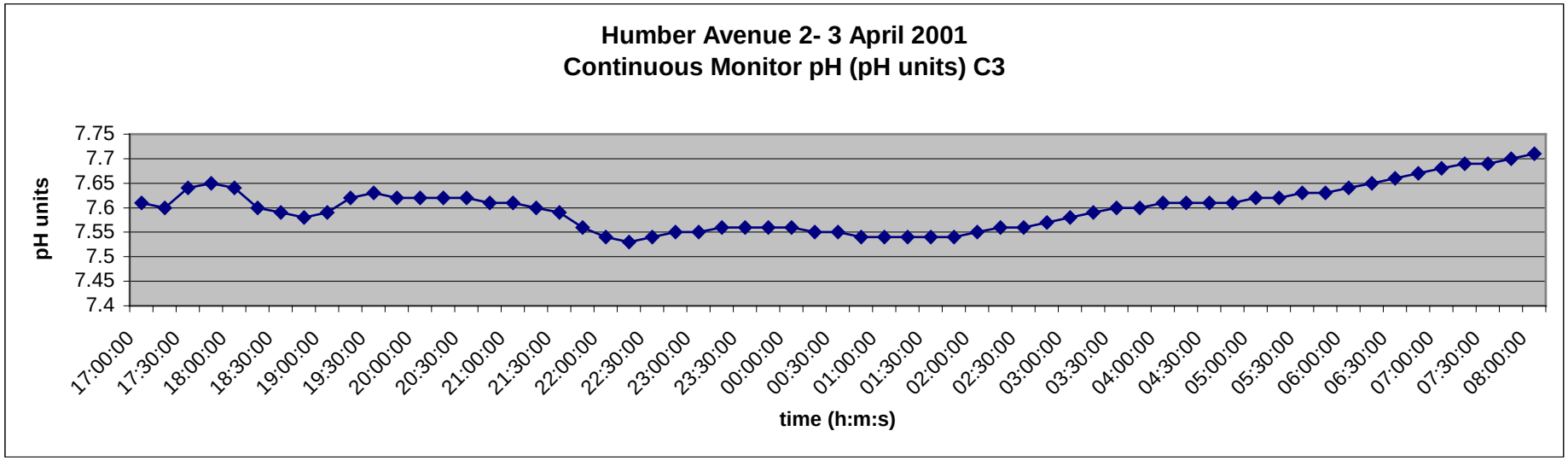


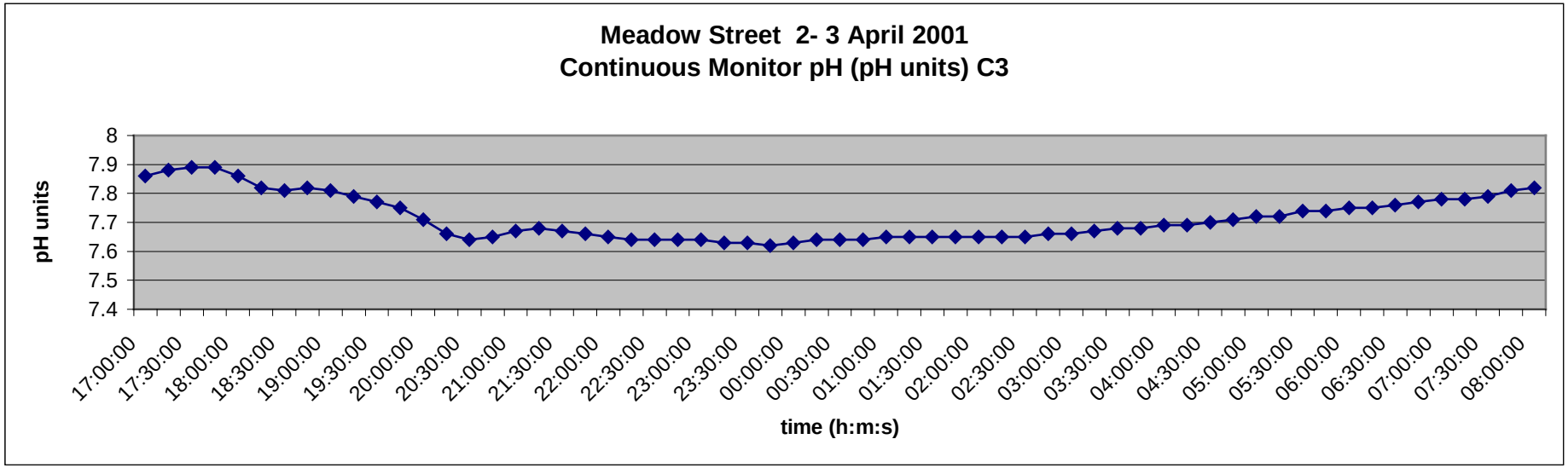

Humber Avenue 2- 3 April 2001
Continuous DO (% saturation) C3
% saturation
88
86
84
82
80
78
76
74
72
70
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)

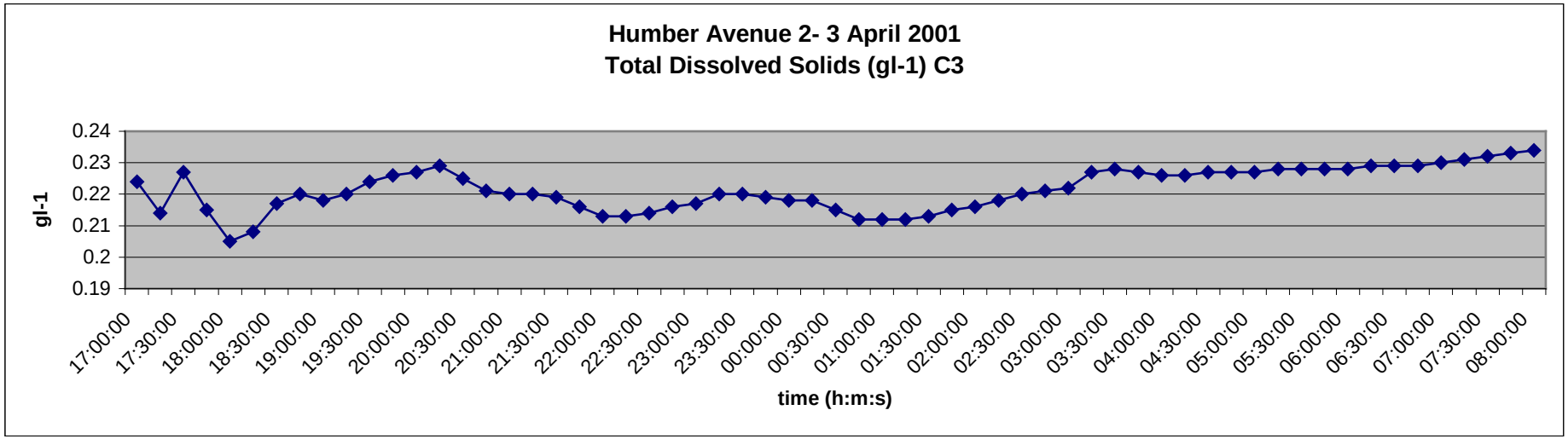

Meadow Street 2- 3 April 2001
Continuous DO (% saturation)
% saturation
85
80
75
70
65
60
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)

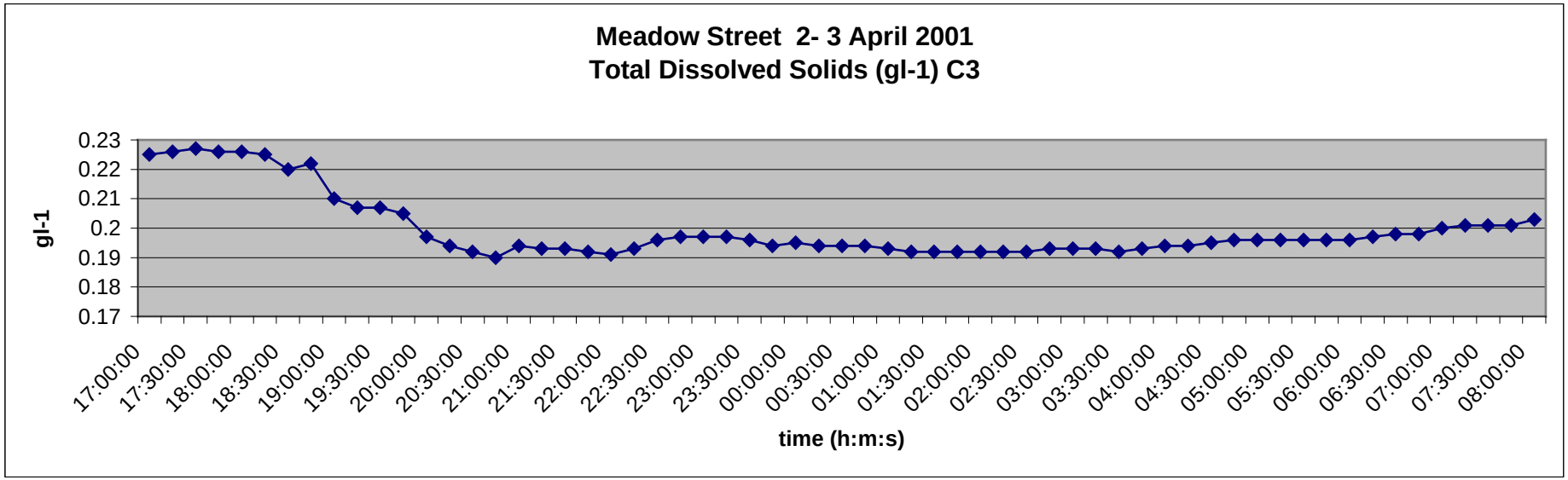

Humber Avenue 2- 3 April 2001
Continuous Ammonium (N) (mgl-1) C3
mgl-1
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)

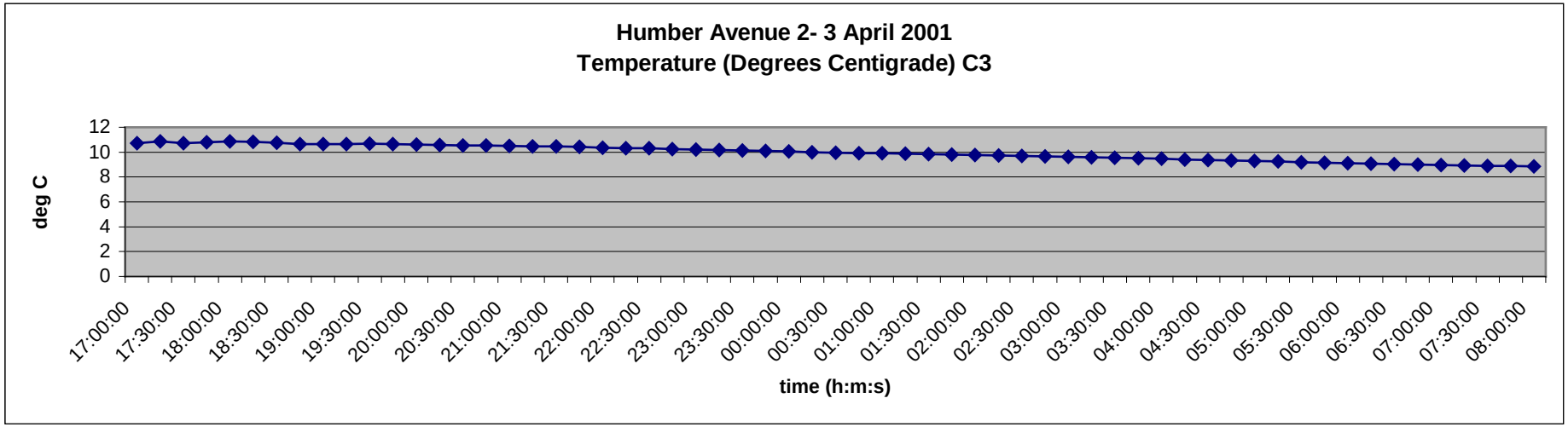

Meadow Street 2- 3 April 2001
Continuous Ammonium (N) (mgl-1) C3
mgl-1
1.2
1
0.8
0.6
0.4
0.2
0
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)

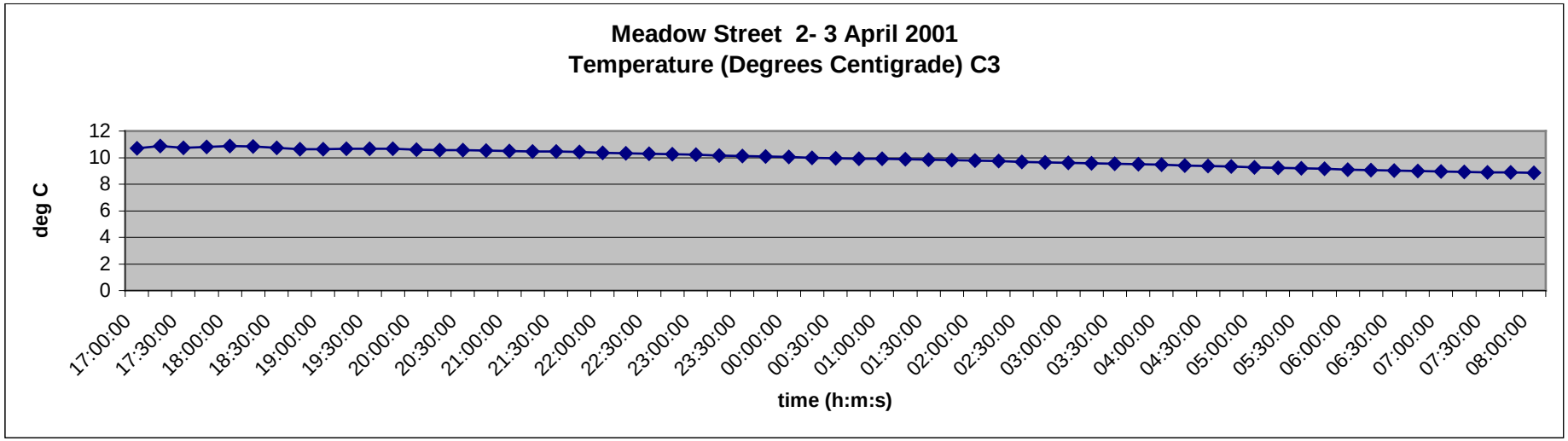

Humber Avenue 2- 3 April 2001
Continuous Monitor pH (pH units) C3
pH units
7.75
7.7
7.65
7.6
7.55
7.5
7.45
7.4
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)


Meadow Street 2- 3 April 2001
Continuous Monitor pH (pH units) C3
pH units
8
7.9
7.8
7.7
7.6
7.5
7.4
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)

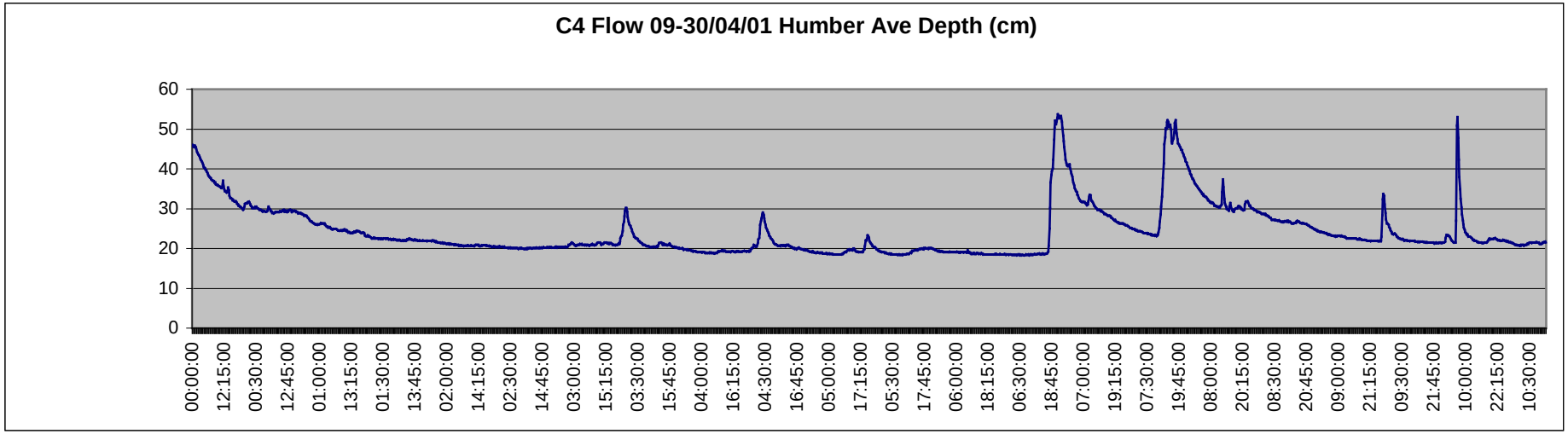

Humber Avenue 2- 3 April 2001
Total Dissolved Solids (gl-1) C3
gl-1
0.24
0.23
0.22
0.21
0.2
0.19
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)

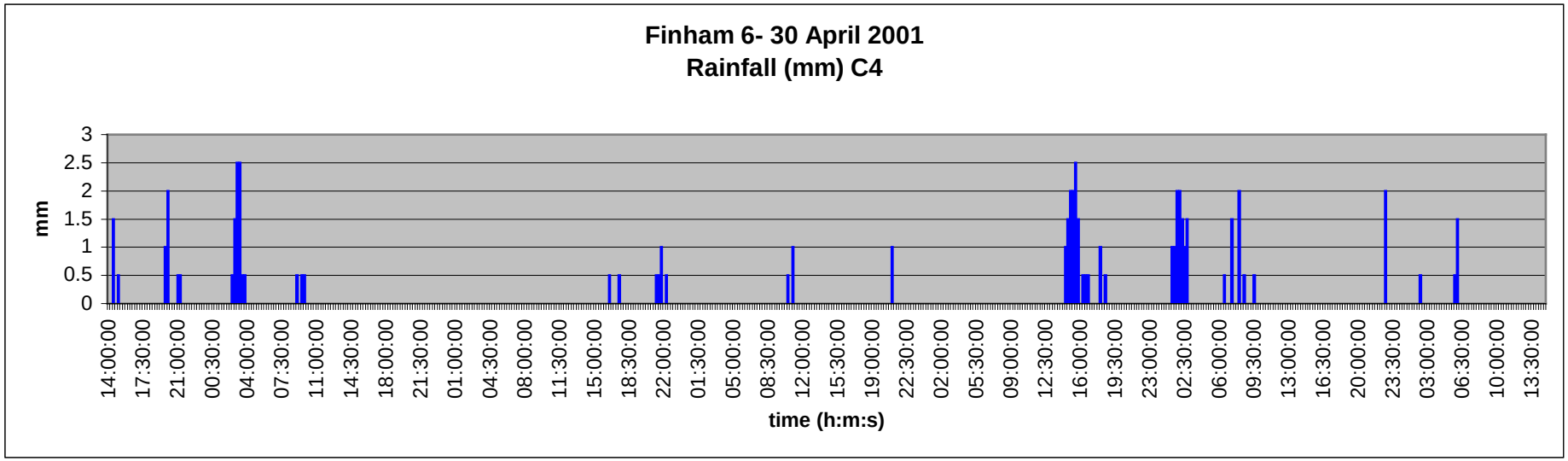

Meadow Street 2- 3 April 2001
Total Dissolved Solids (gl-1) C3
gl-1
0.23
0.22
0.21
0.2
0.19
0.18
0.17
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)

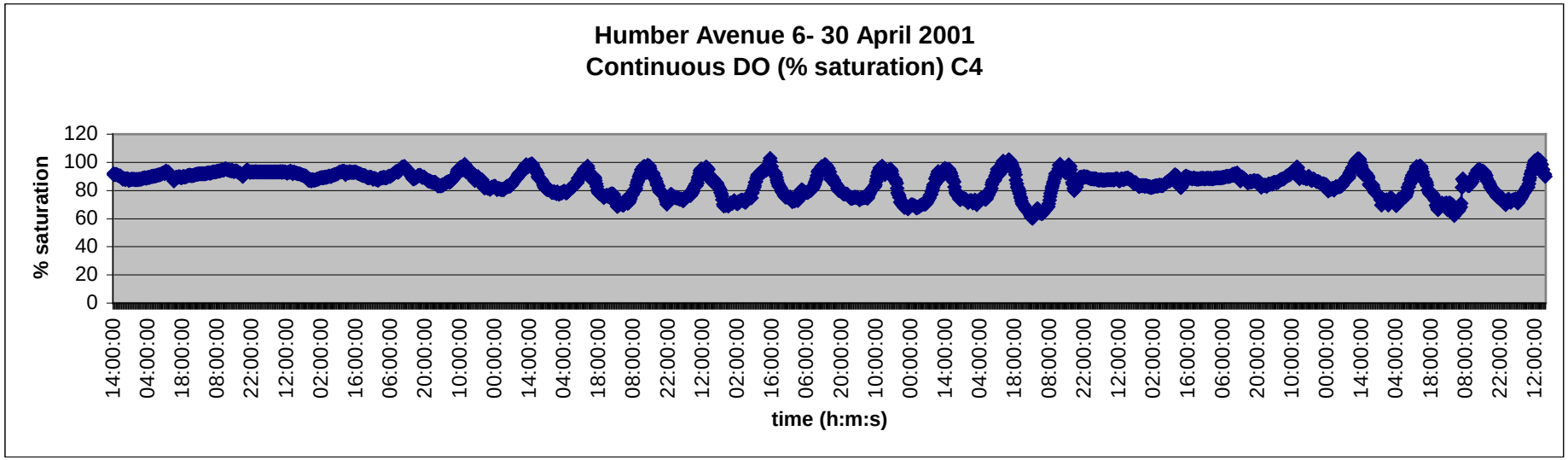

Humber Avenue 2- 3 April 2001
Temperature (Degrees Centigrade) C3
deg C
12
10
8
6
4
2
0
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)

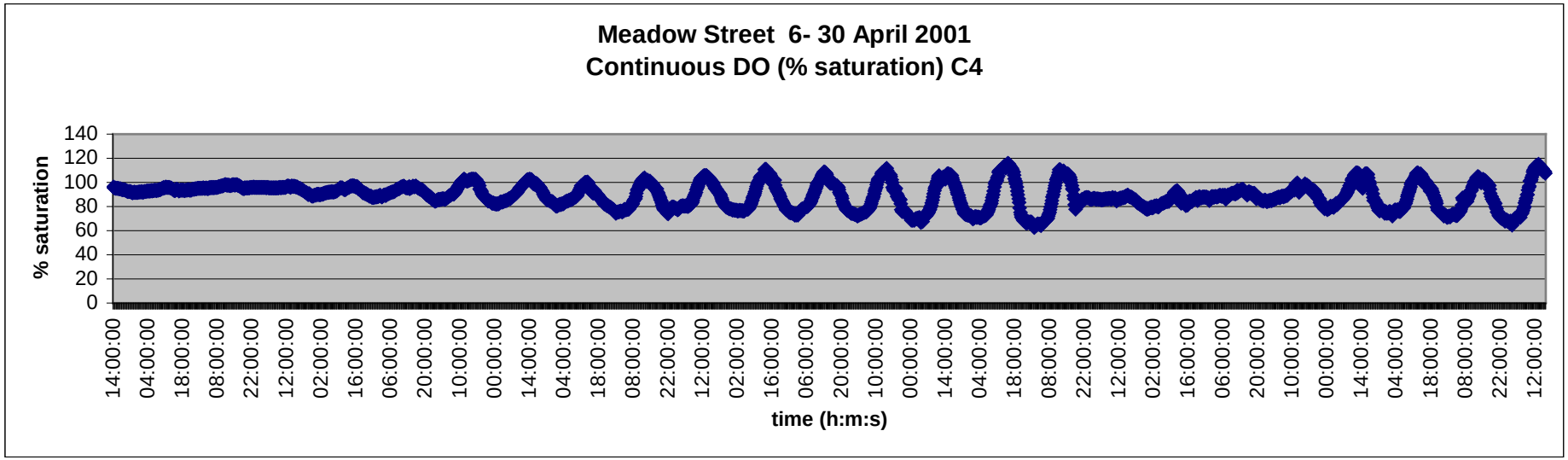

Meadow Street 2- 3 April 2001
Temperature (Degrees Centigrade) C3
deg C
12
10
8
6
4
2
0
17:00:00
17:30:00
18:00:00
18:30:00
19:00:00
19:30:00
20:00:00
20:30:00
21:00:00
21:30:00
22:00:00
22:30:00
23:00:00
23:30:00
00:00:00
00:30:00
01:00:00
01:30:00
02:00:00
02:30:00
03:00:00
03:30:00
04:00:00
04:30:00
05:00:00
05:30:00
06:00:00
06:30:00
07:00:00
07:30:00
08:00:00
time (h:m:s)

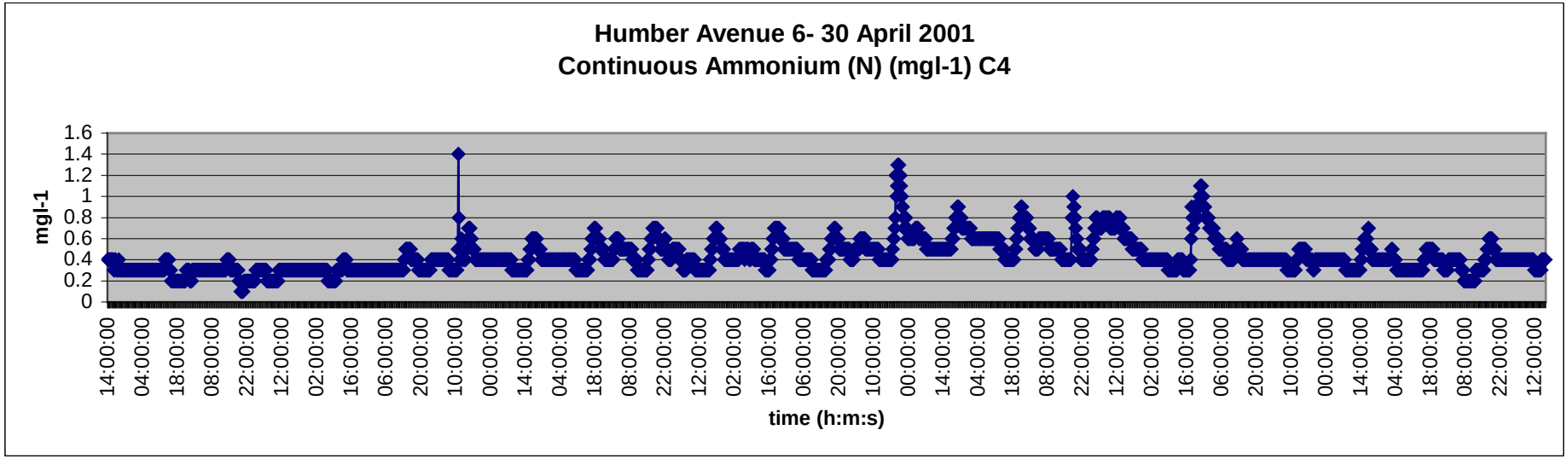
C4 Depth and Continuous monitors

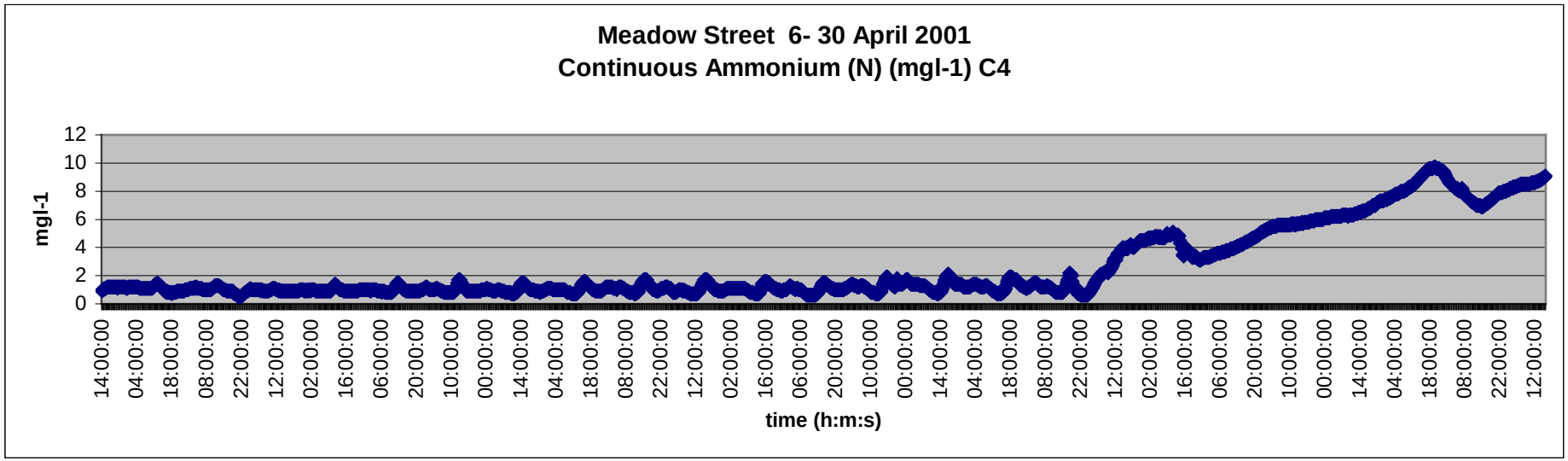


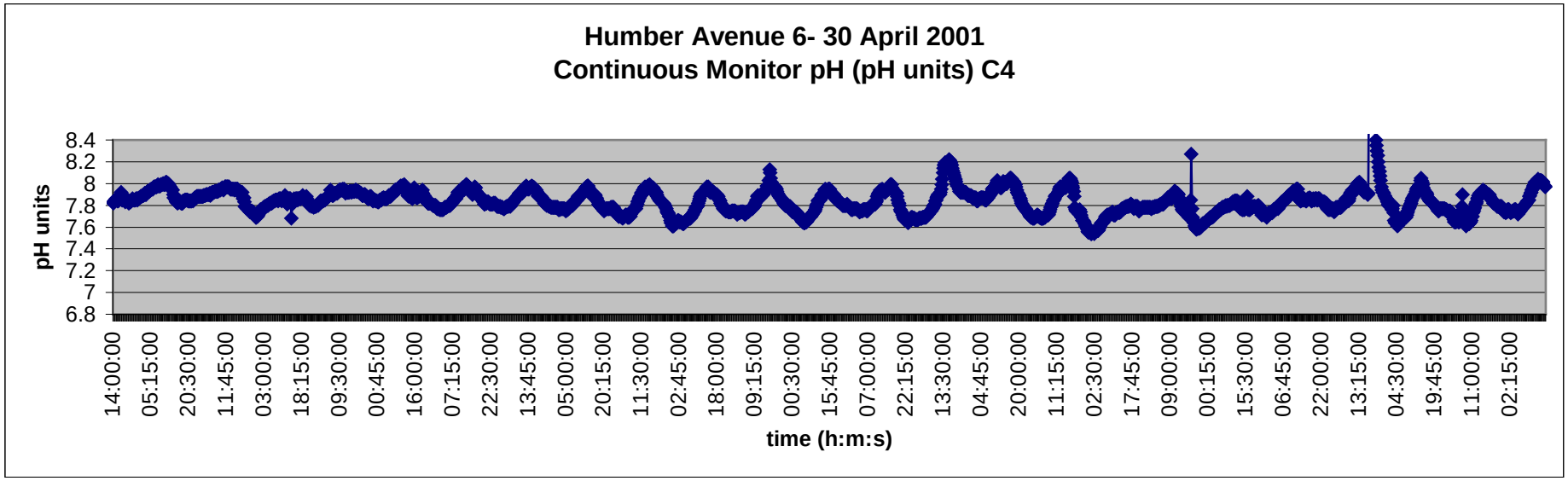


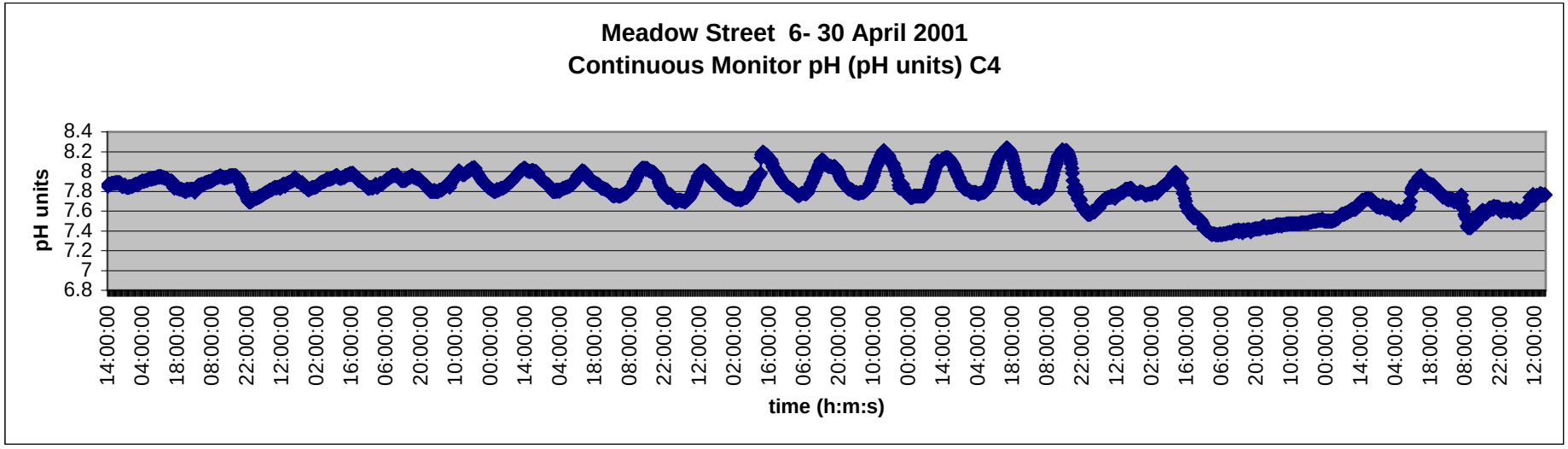

Humber Avenue 6- 30 April 2001
Continuous DO (% saturation) C4
% saturation
120
100
80
60
40
20
0
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
time (h:m:s)

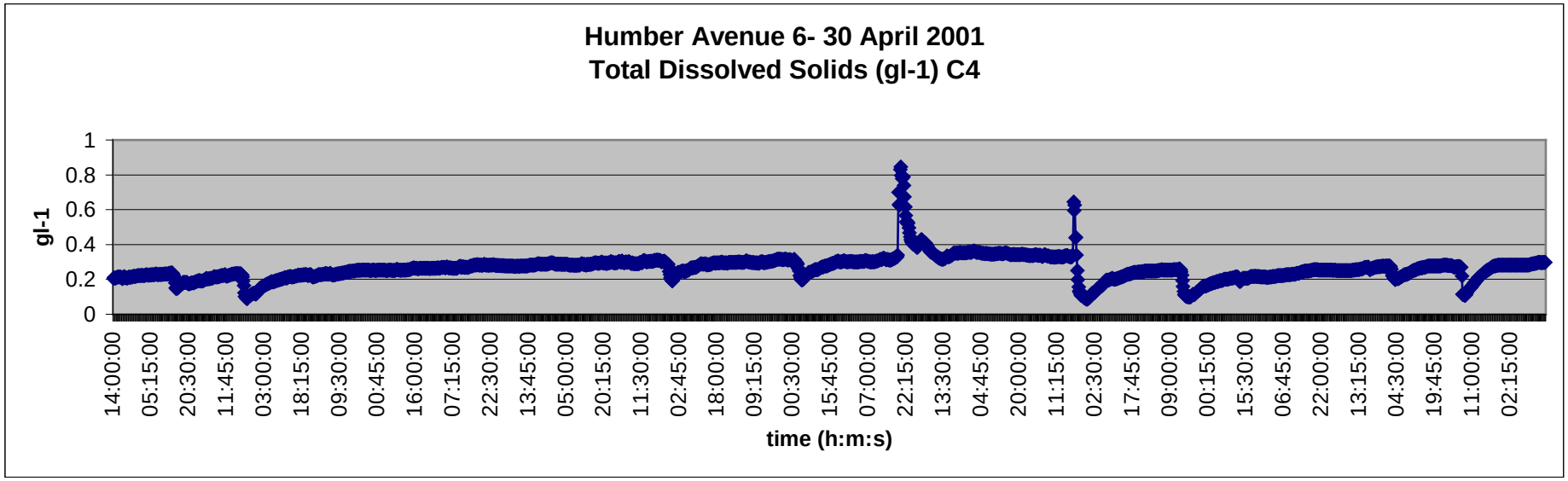

Meadow Street 6- 30 April 2001
Continuous DO (% saturation) C4
% saturation
140
120
100
80
60
40
20
0
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
time (h:m:s)

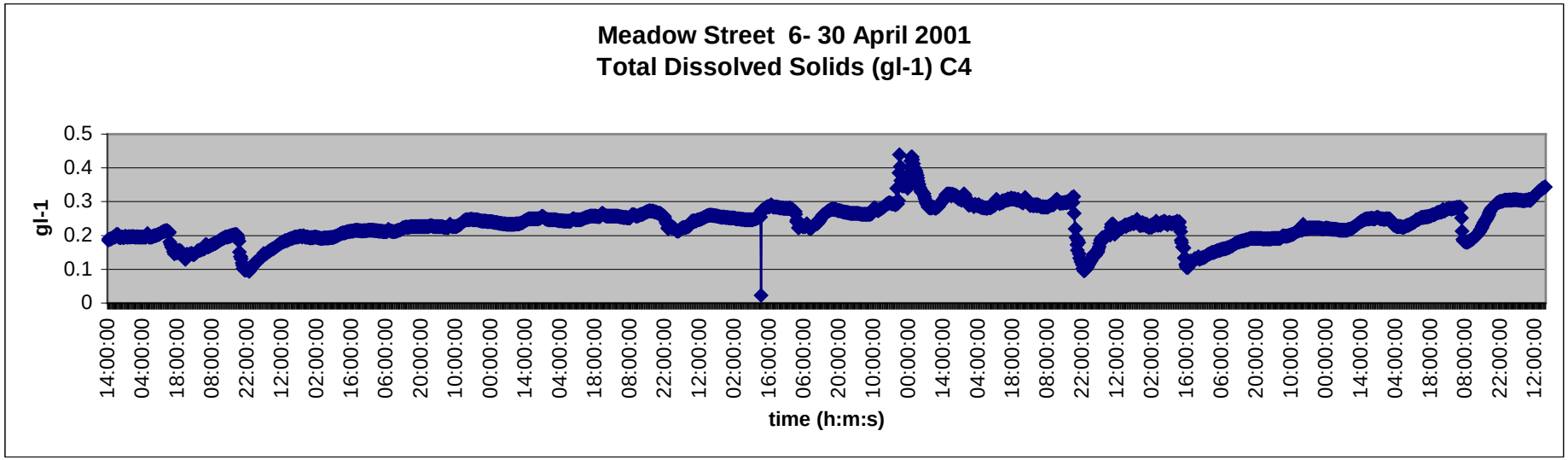

Humber Avenue 6- 30 April 2001
Continuous Ammonium (N) (mgl-1) C4
mgl-1
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
time (h:m:s)

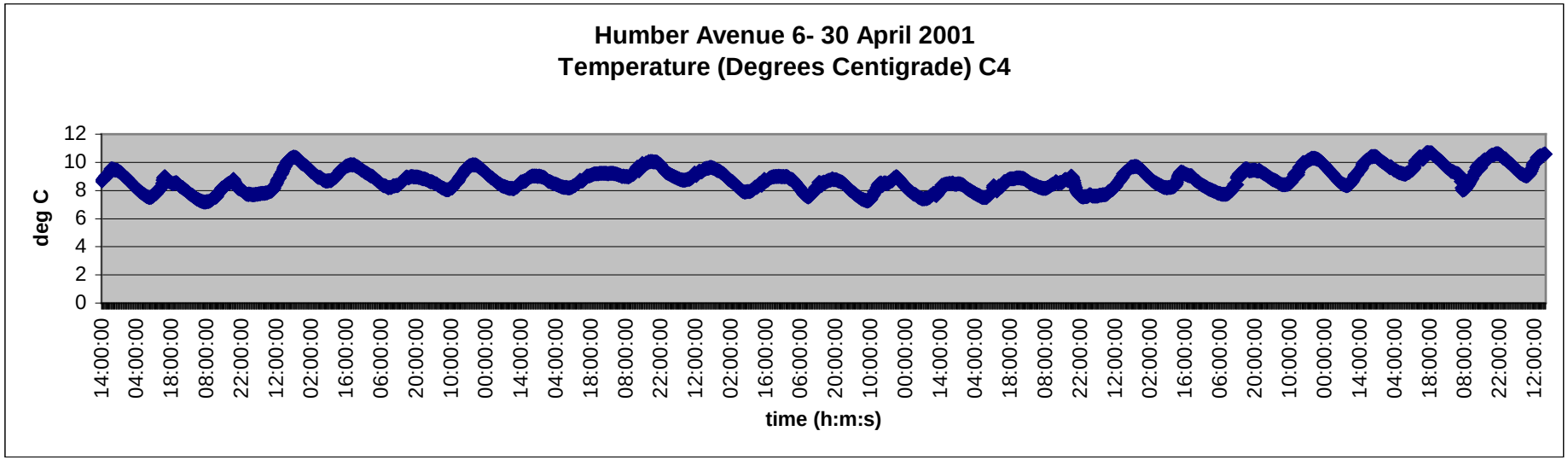

Meadow Street 6- 30 April 2001
Continuous Ammonium (N) (mgl-1) C4
mgl-1
12
10
8
6
4
2
0
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
time (h:m:s)


Humber Avenue 6- 30 April 2001
Continuous Monitor pH (pH units) C4
pH units
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
14:00:00
05:15:00
20:30:00
11:45:00
03:00:00
18:15:00
09:30:00
00:45:00
16:00:00
07:15:00
22:30:00
13:45:00
05:00:00
20:15:00
11:30:00
02:45:00
18:00:00
09:15:00
00:30:00
15:45:00
07:00:00
22:15:00
13:30:00
04:45:00
20:00:00
11:15:00
02:30:00
17:45:00
09:00:00
00:15:00
15:30:00
06:45:00
22:00:00
13:15:00
04:30:00
19:45:00
11:00:00
02:15:00
time (h:m:s)


Meadow Street 6- 30 April 2001
Continuous Monitor pH (pH units) C4
pH units
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
time (h:m:s)


Humber Avenue 6- 30 April 2001
Total Dissolved Solids (gl-1) C4
gl-1
1
0.8
0.6
0.4
0.2
0
14:00:00
05:15:00
20:30:00
11:45:00
03:00:00
18:15:00
09:30:00
00:45:00
16:00:00
07:15:00
22:30:00
13:45:00
05:00:00
20:15:00
11:30:00
02:45:00
18:00:00
09:15:00
00:30:00
15:45:00
07:00:00
22:15:00
13:30:00
04:45:00
20:00:00
11:15:00
02:30:00
17:45:00
09:00:00
00:15:00
15:30:00
06:45:00
22:00:00
13:15:00
04:30:00
19:45:00
11:00:00
02:15:00
time (h:m:s)


Meadow Street 6- 30 April 2001
Total Dissolved Solids (gl-1) C4
gl-1
0.5
0.4
0.3
0.2
0.1
0
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
time (h:m:s)


Humber Avenue 6- 30 April 2001
Temperature (Degrees Centigrade) C4
deg C
0
2
4
6
8
10
12
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
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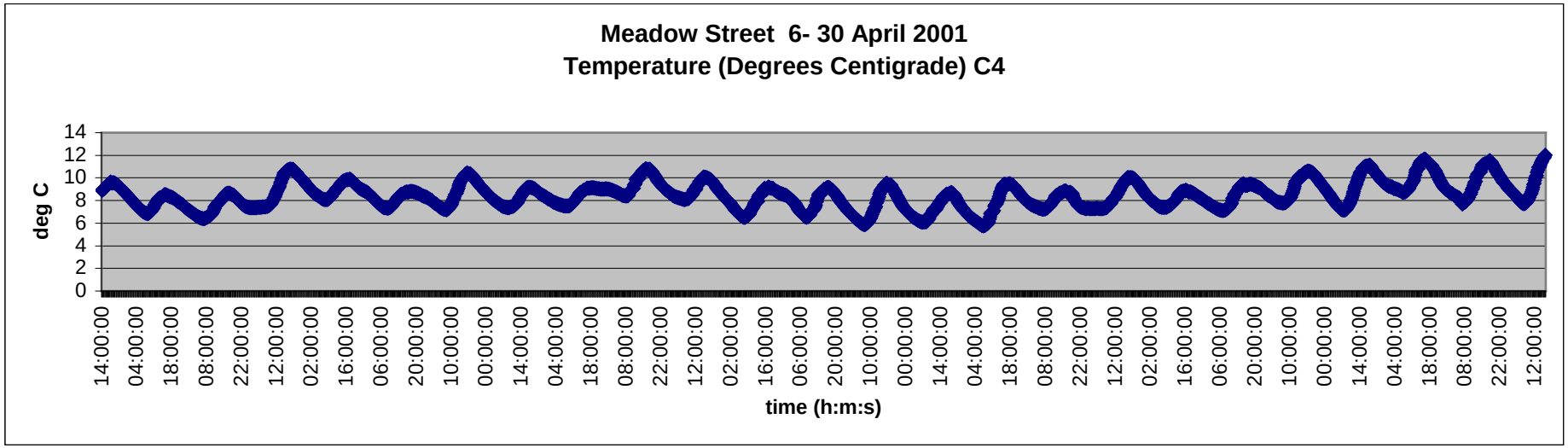
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
time (h:m:s)


Meadow Street 6- 30 April 2001
Temperature (Degrees Centigrade) C4
deg C
0
2
4
6
8
10
12
14
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
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20:00:00
10:00:00
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04:00:00
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08:00:00
22:00:00
12:00:00
02:00:00
16:00:00
06:00:00
20:00:00
10:00:00
00:00:00
14:00:00
04:00:00
18:00:00
08:00:00
22:00:00
12:00:00
time (h:m:s)

Appendix 7.1 Storm event 15th – 17th March 2001.

Figure a) Depth at Humber Avenue 15-17 March 2001

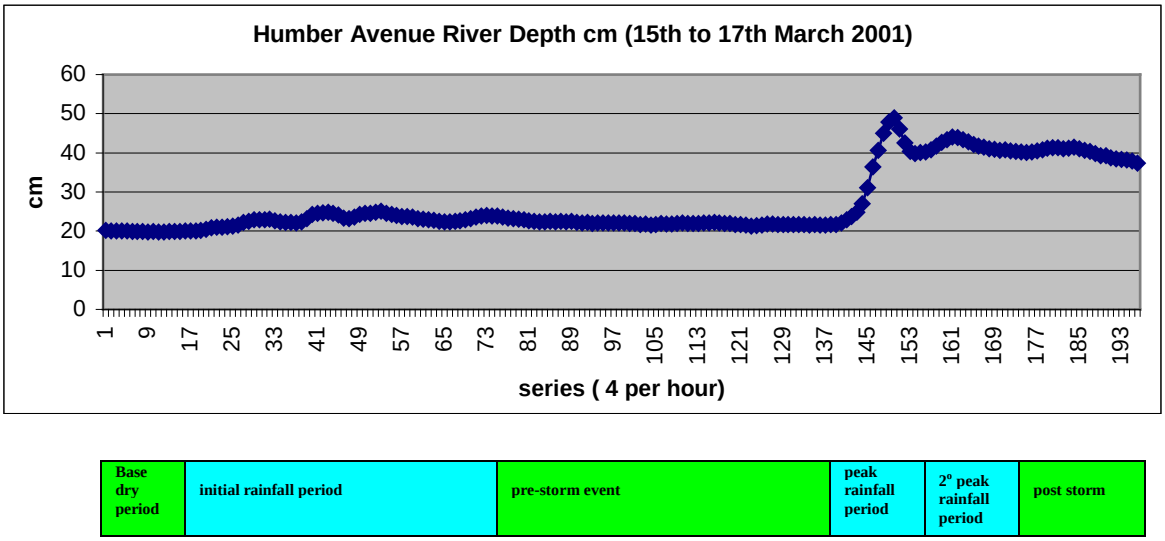


Figure b) Flow at Humber Avenue 15-17 March 2001

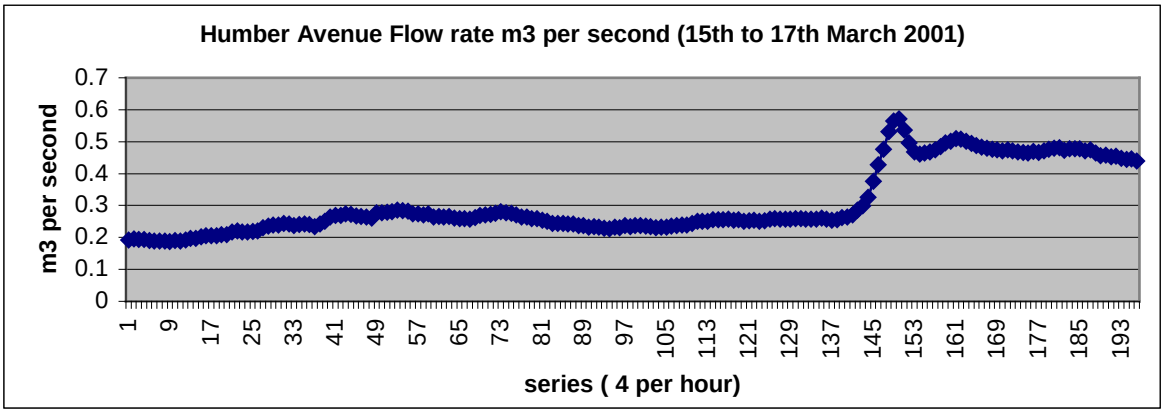


Figure c) Rainfall at Humber Avenue 15-17 March 2001

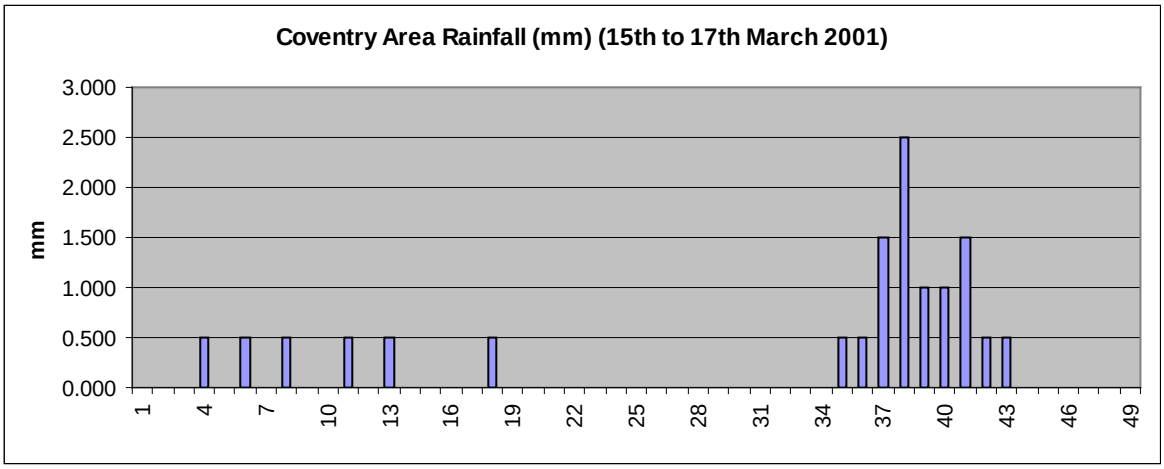
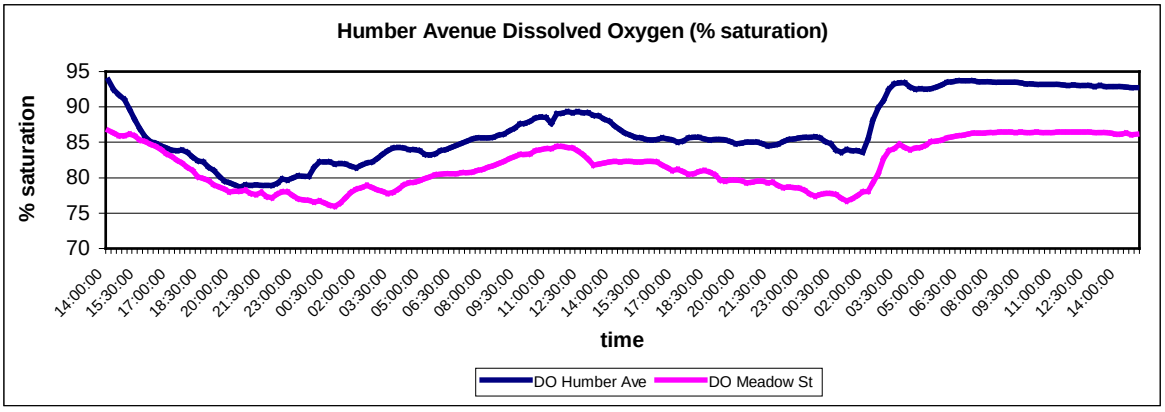
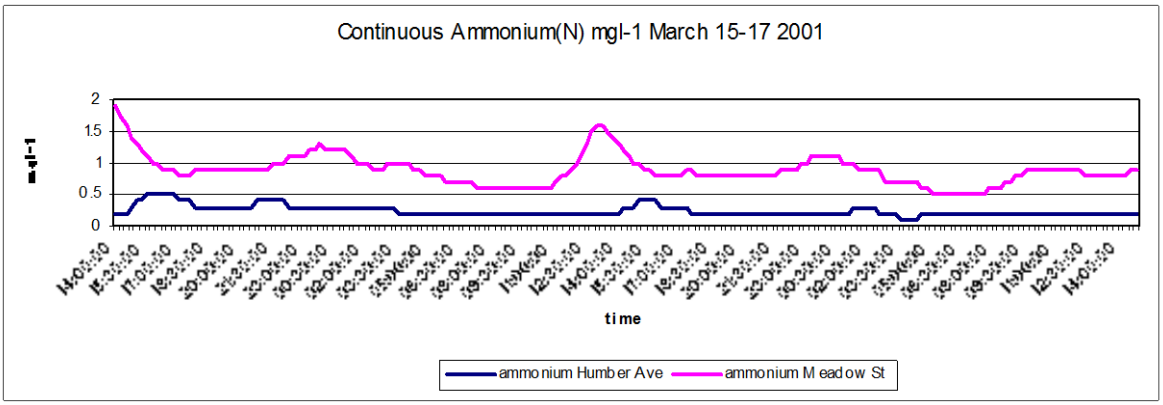


Figure d) Dissolved Oxygen at both sites 15-17 March 2001



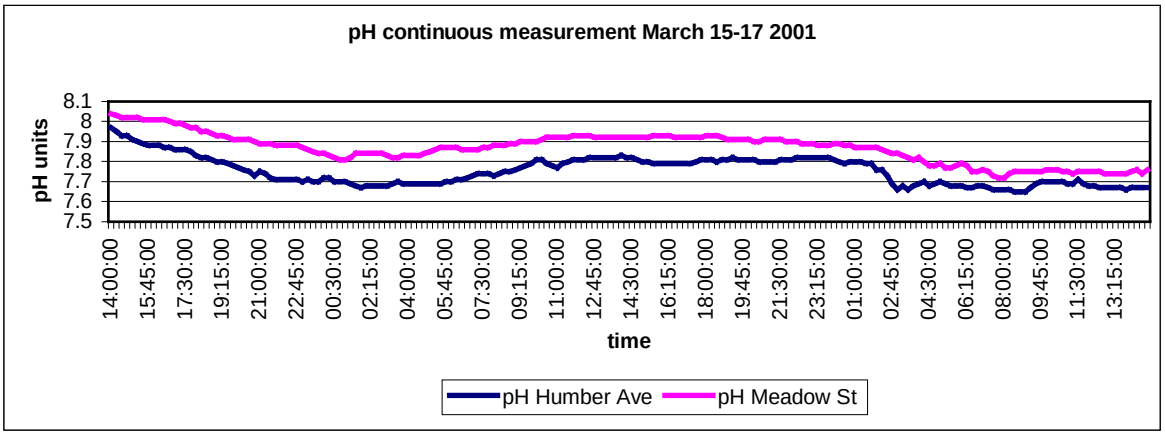
Base dry period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

Figure e) Ammonium results at both sites 15-17 March 2001



Base dry period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

Figure f) Continuous monitor pH at both sites 15-17 March 2001



Base dry period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

Figure g) Continuous monitor TDS at both sites 15-17 March 2001

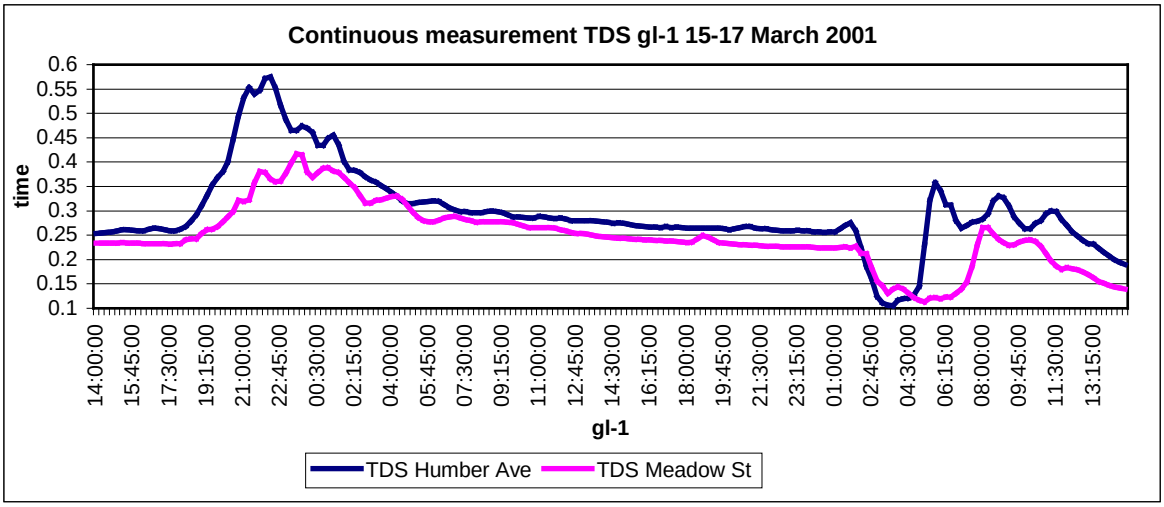


Figure h) Continuous monitor temperature at both sites 15-17 March 2001

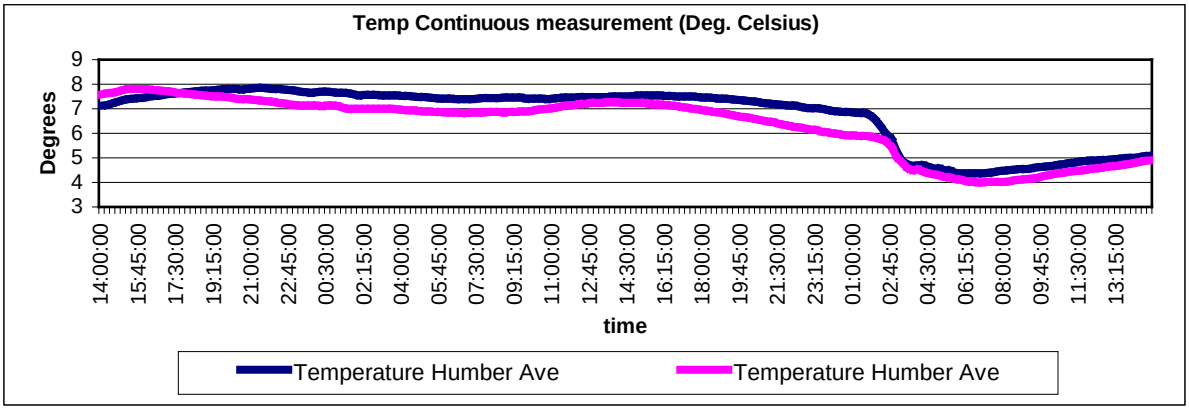
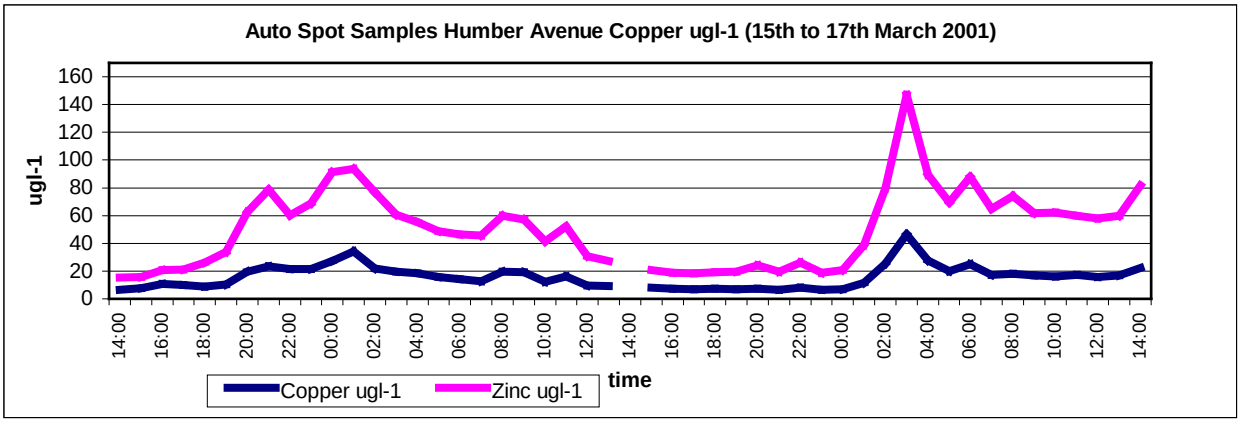


Figure i) Auto-sample results – Cu and Zn Humber Ave 15-17 March 2001



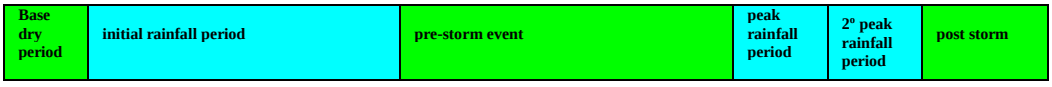
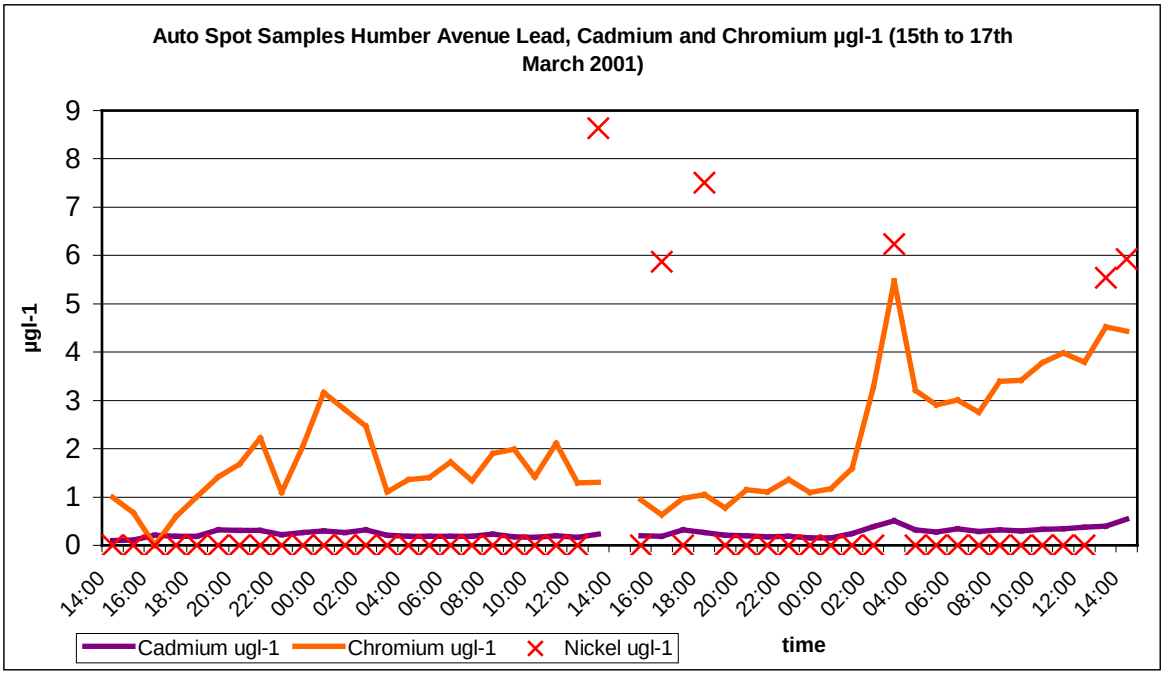
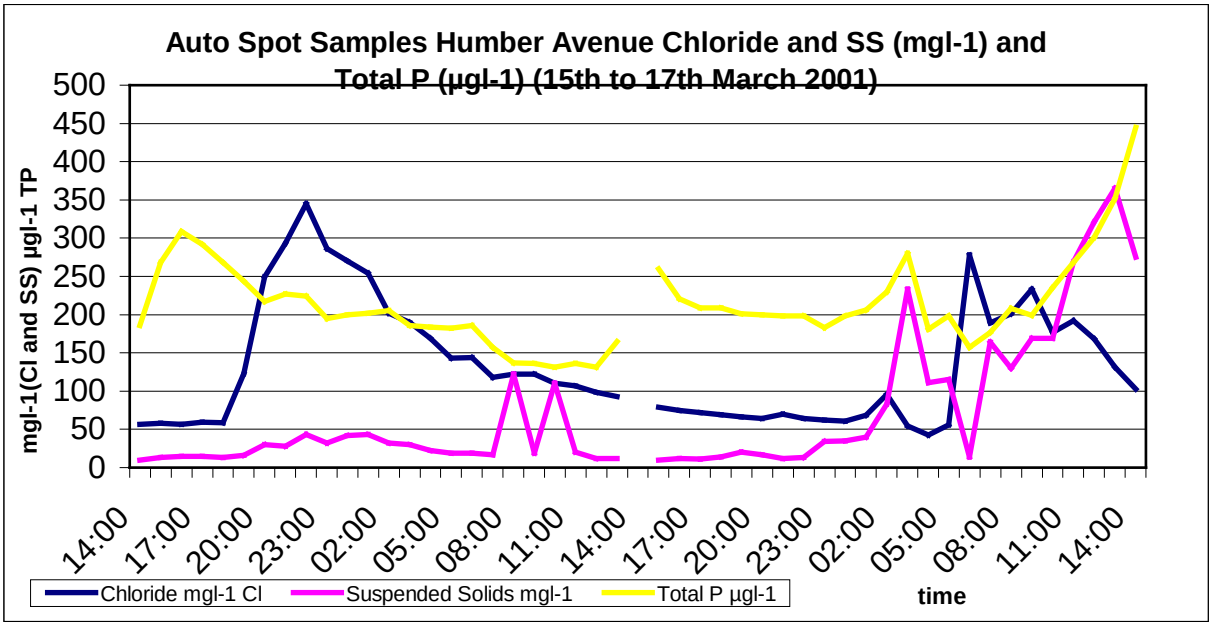


Figure j) Auto-sample results – Pb, Cd and Cr Humber Ave 15-17 March 2001



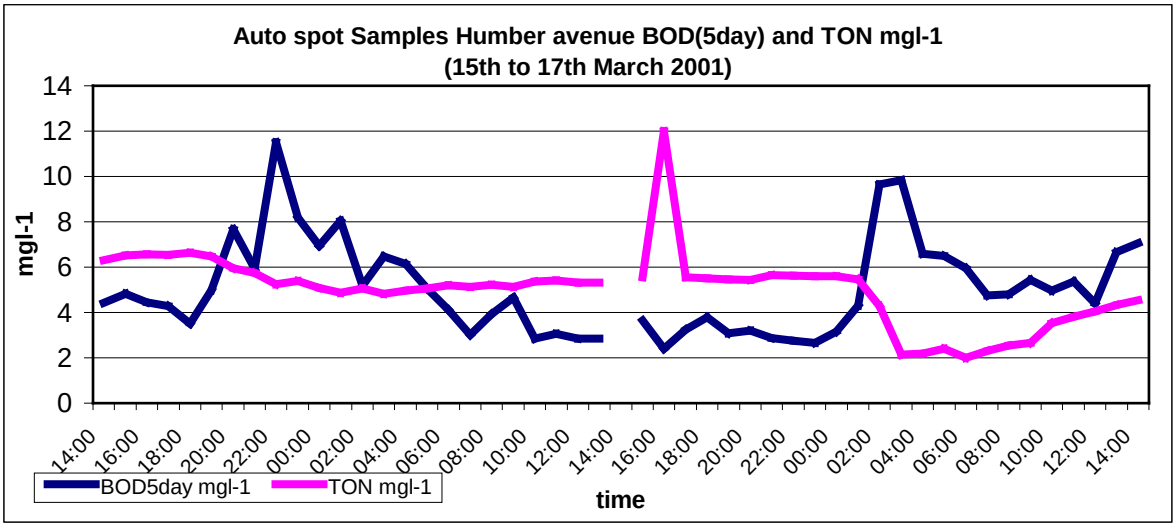
Base dry period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

Figure k) Auto-sample results – Cl, SS and Total P. Humber Ave 15-17 March 2001



Base dry period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

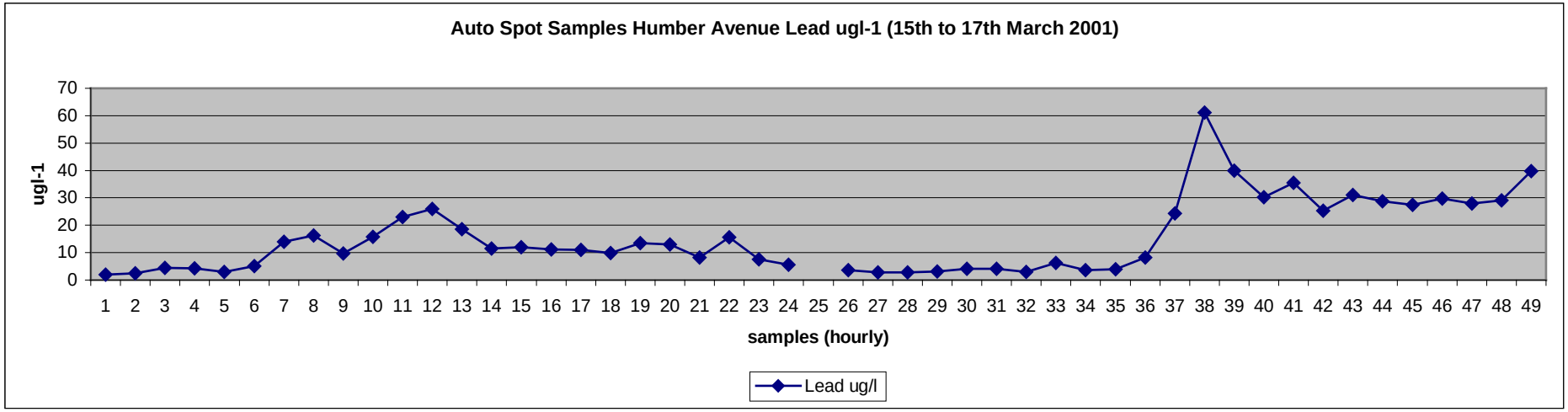
Figure l) Auto-sample results – BOD and TON Humber Ave 15-17 March 2001



Base dry period	initial rainfall period	pre-storm event	peak rainfall period	2^{o} peak rainfall period	post storm

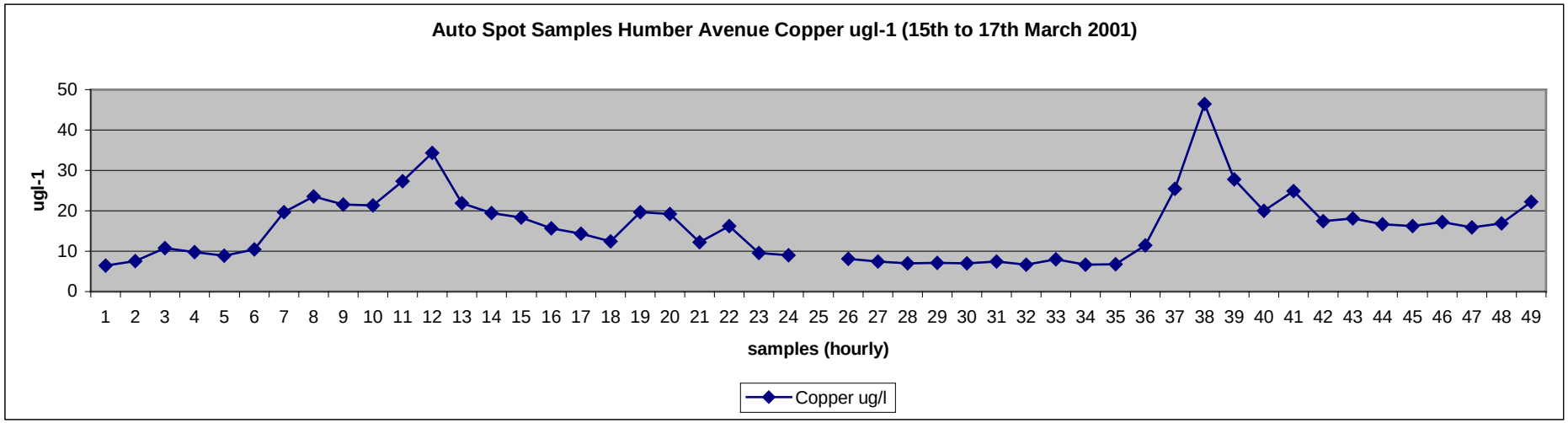
Appendix 7.2: Auto Spot sampling results – Humber Avenue only

7.2a) Lead

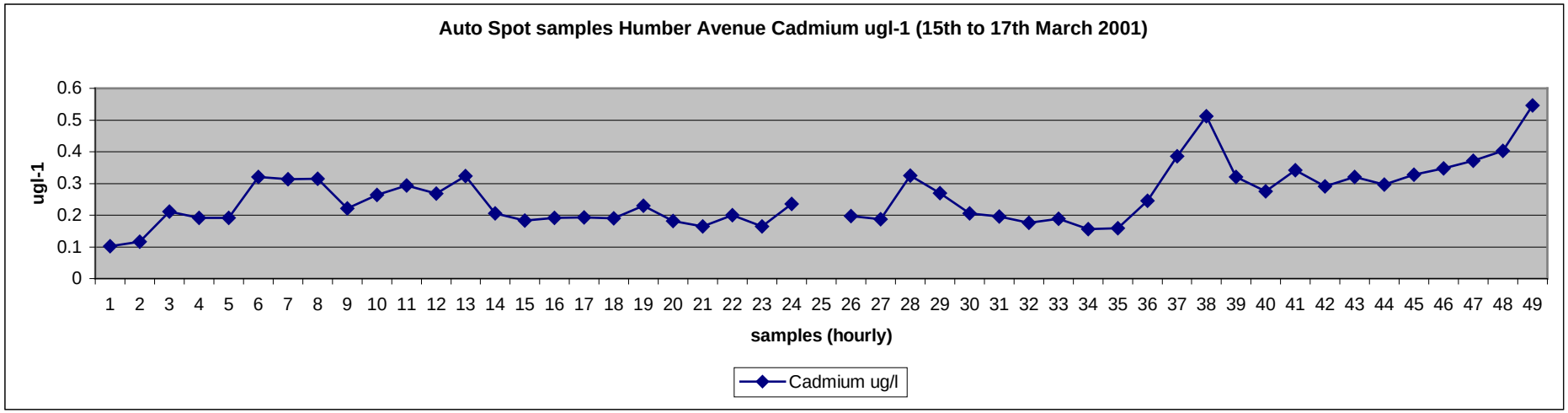


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

7.2b) Copper

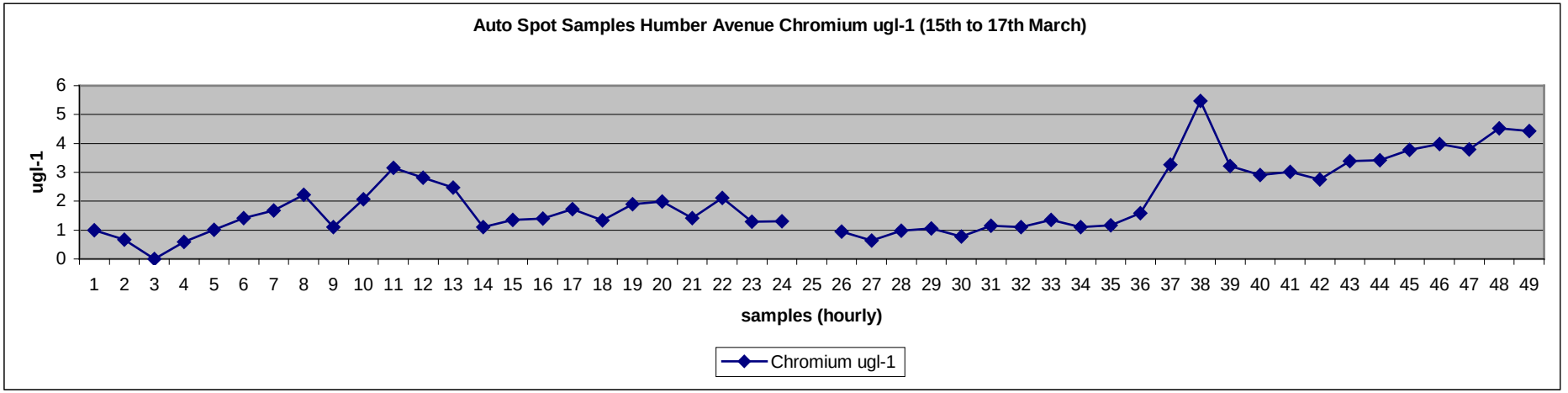


7.2c) Cadmium

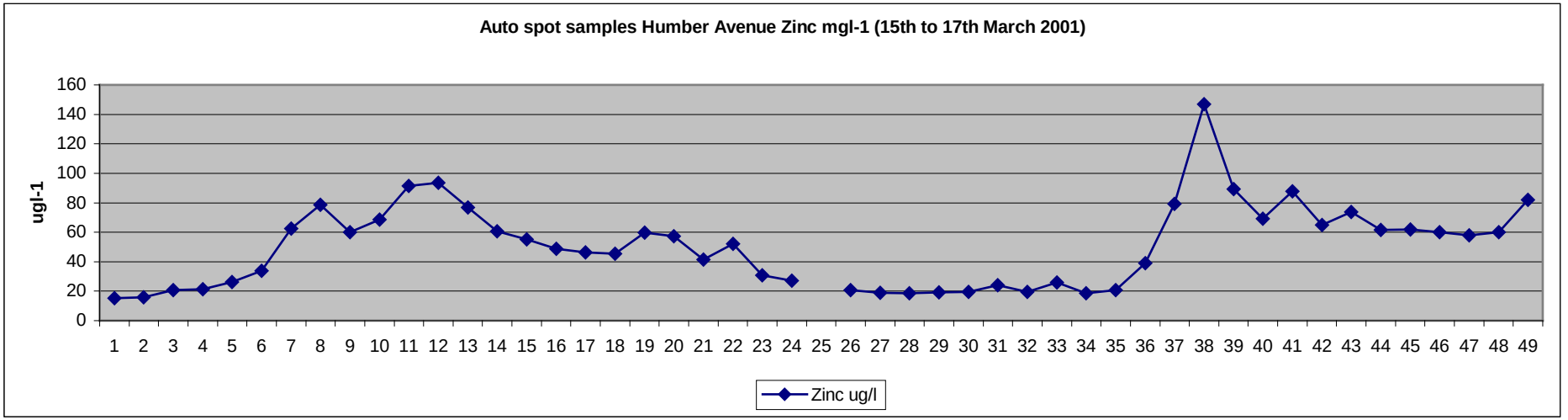


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2° peak rainfall period	post storm

7.2d) Chromium

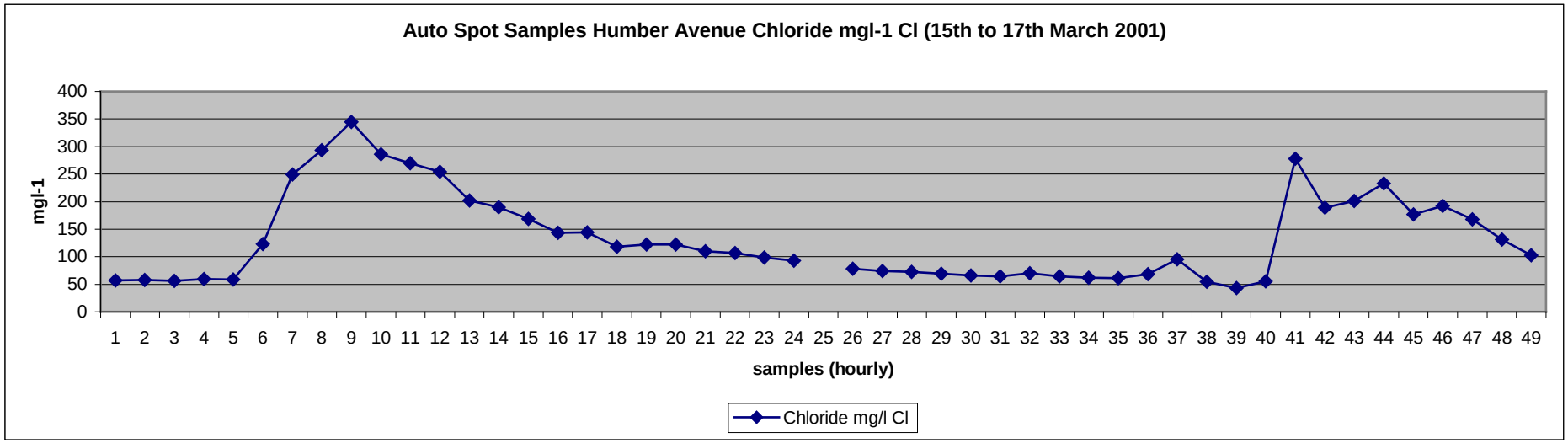


7.2e) Zinc

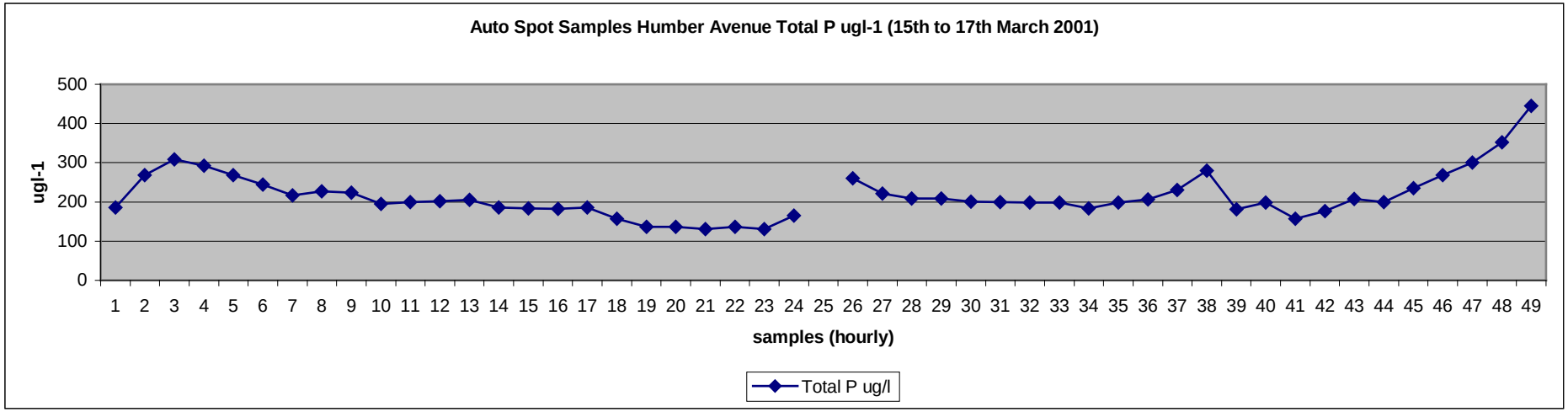


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2° peak rainfall period	post storm

7.2f) Chloride

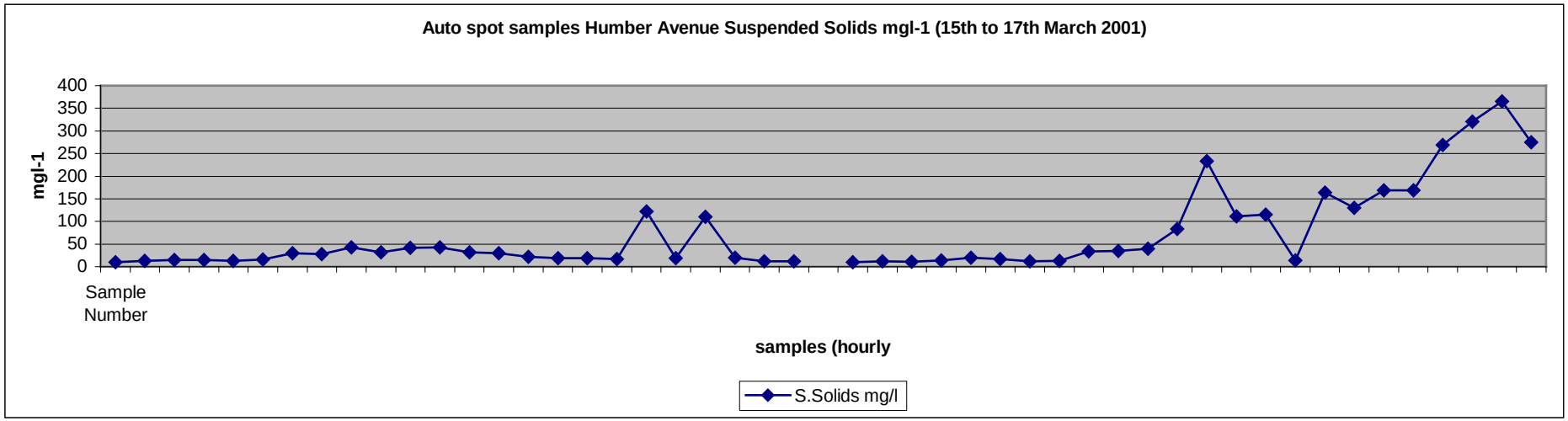


7.2g) Total P

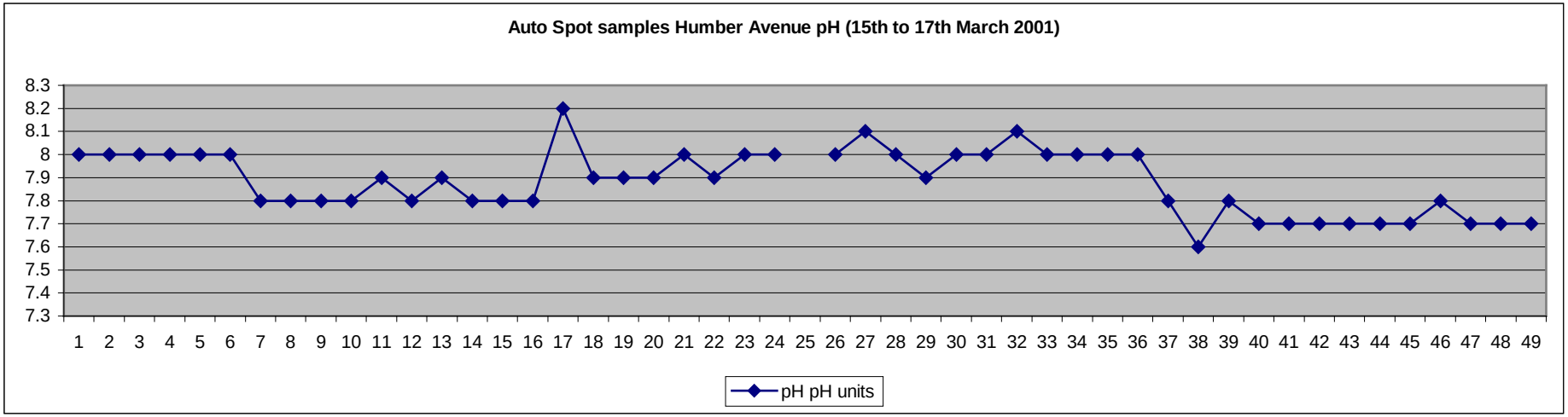


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2° peak rainfall period	post storm

7.2h) Suspended Solids

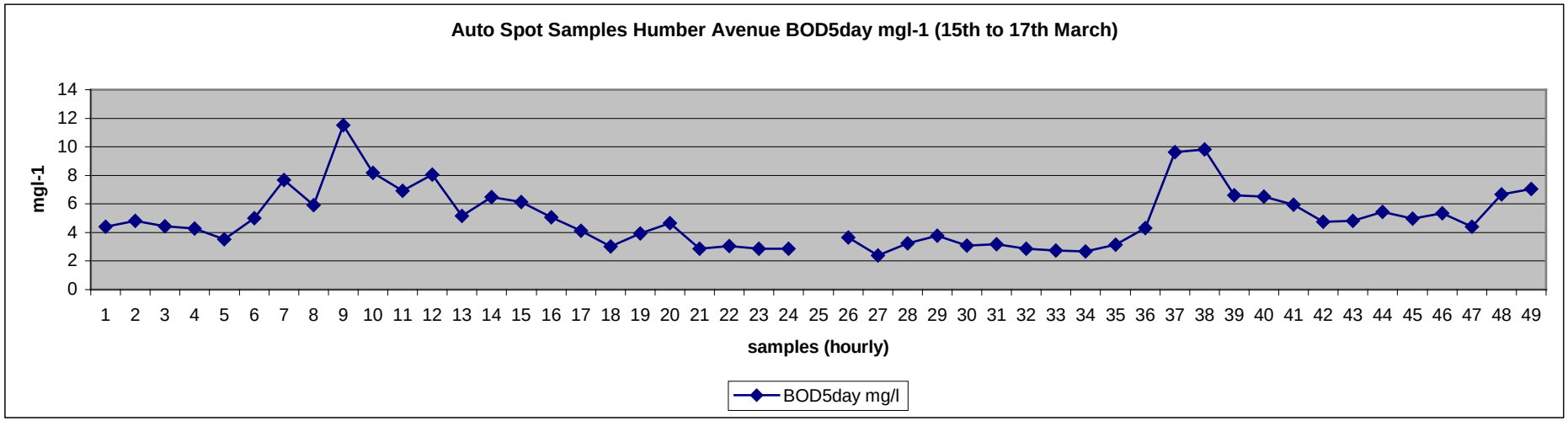


7.2i) pH

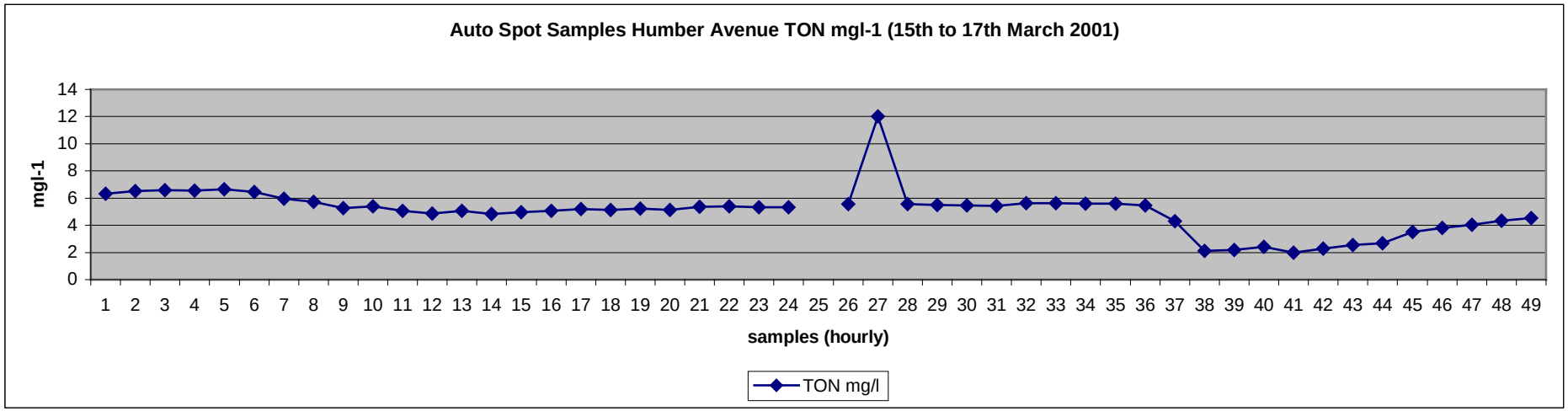


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2° peak rainfall period	post storm

7.2j) Biochemical Oxygen Demand (BOD)



7.2k) Total Oxidised Nitrates (TON)

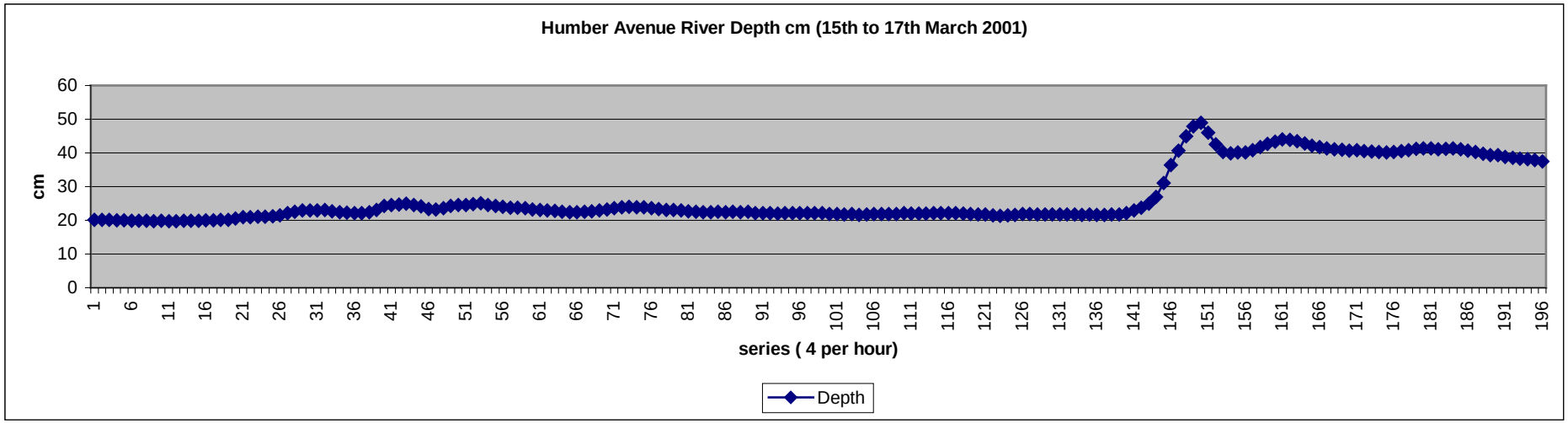


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

Appendix 7.3: Data collected for storm event at Humber Avenue, 15 –17 March 2001.

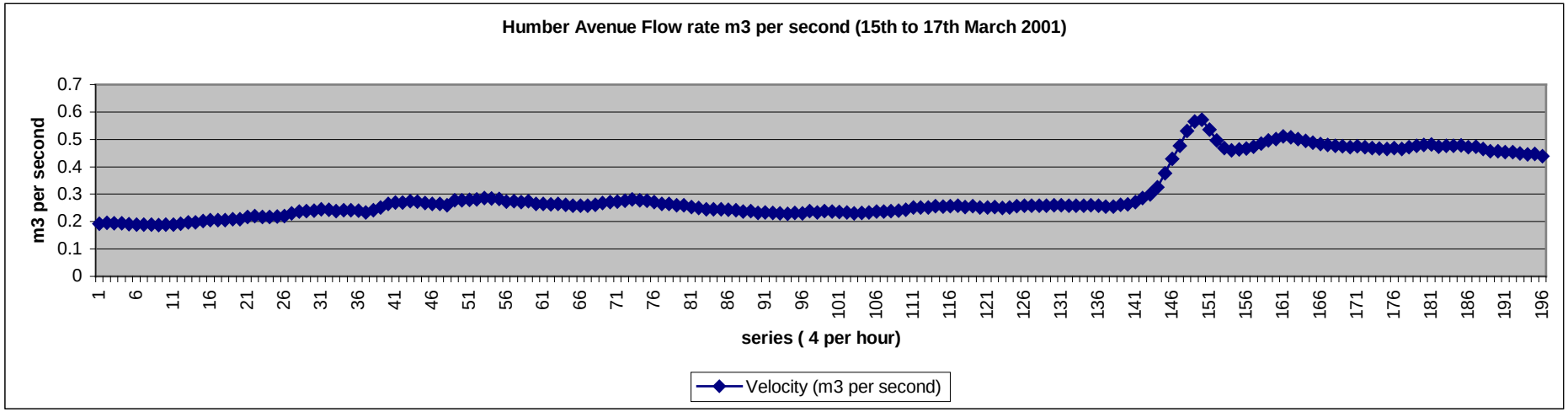
Flow Data

7.3a) Depth

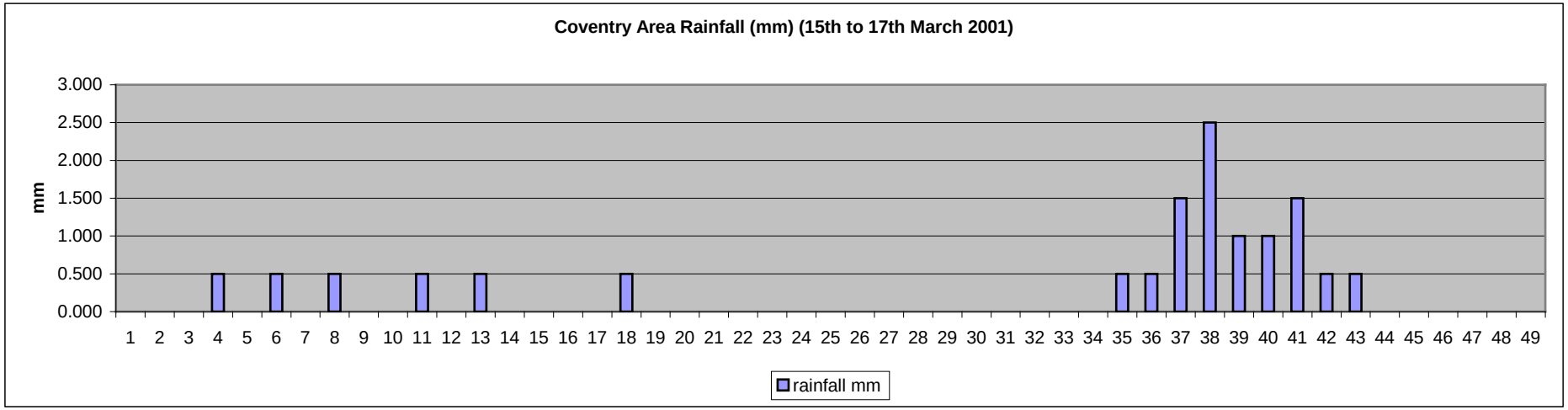


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

7.3b) Flow



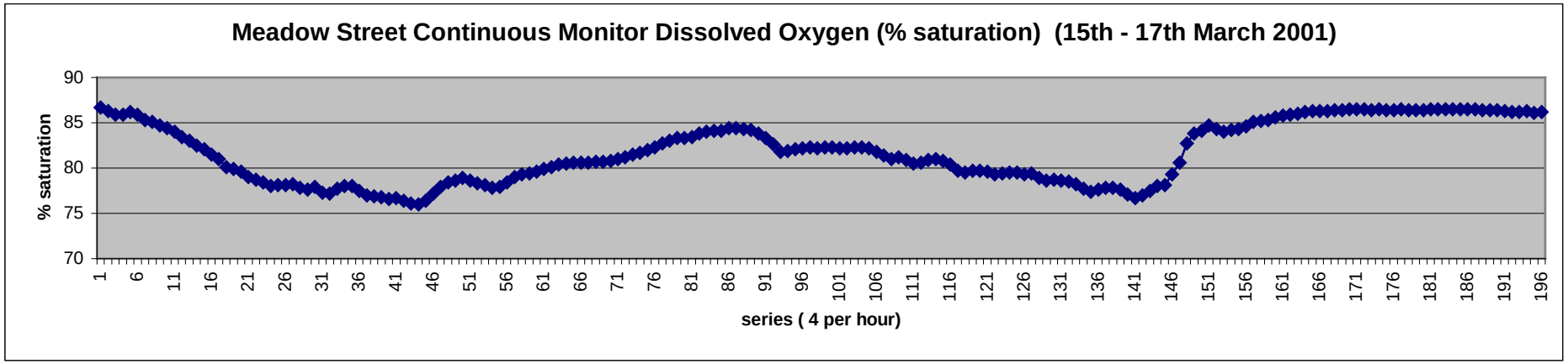
7.3c) Coventry Area Rainfall



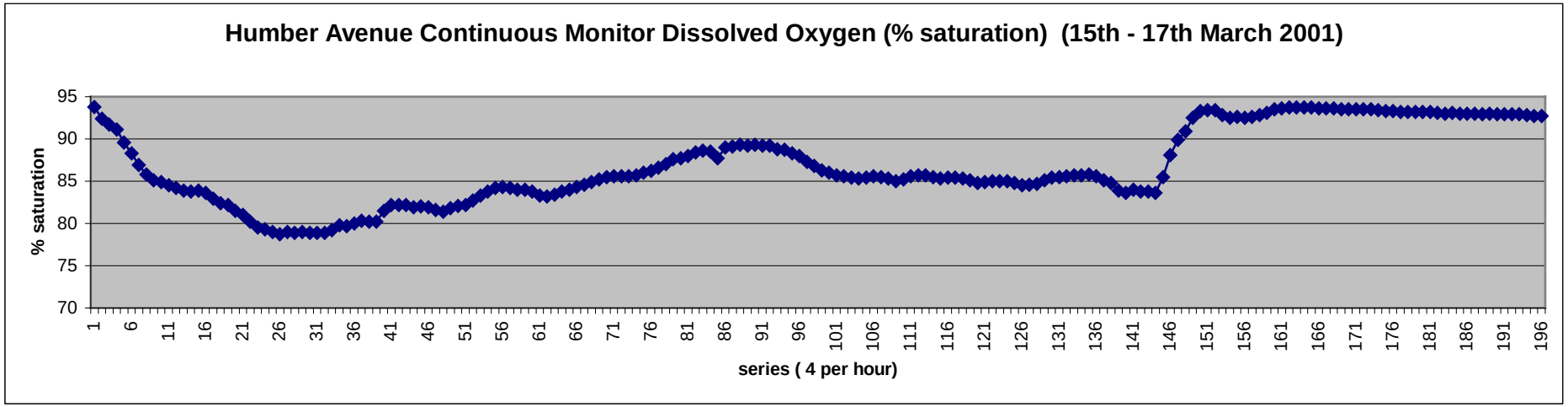
baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

Appendix 7.3: Continuous Water Quality Monitor data

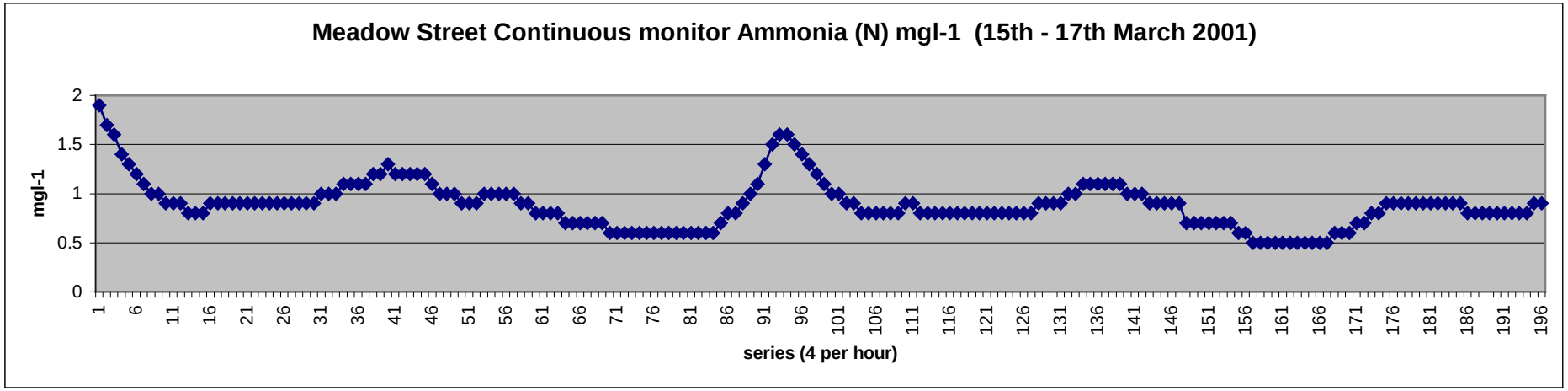
7.3d) Dissolved Oxygen



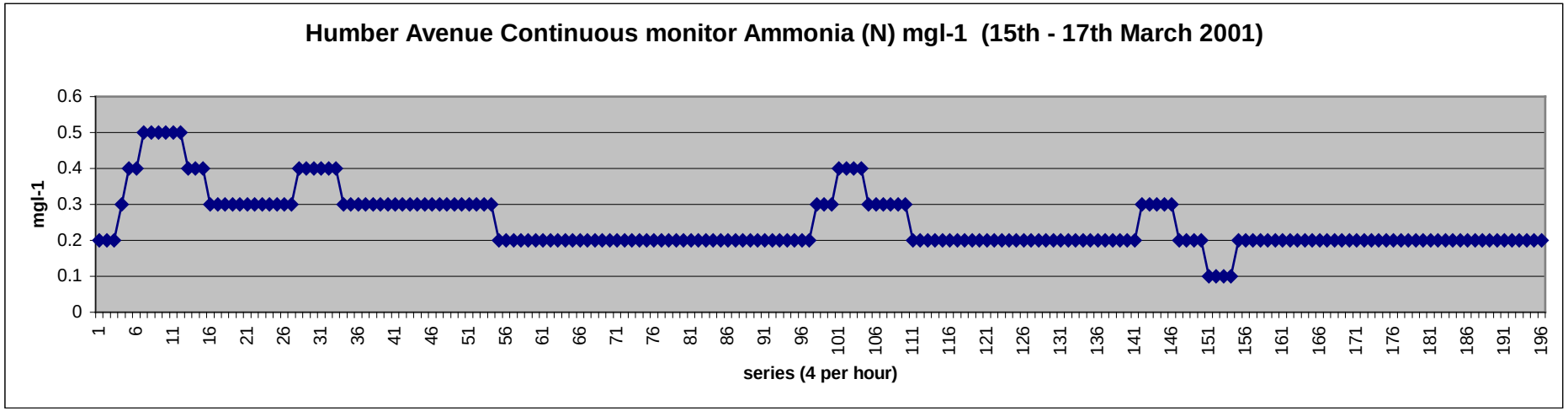
baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm



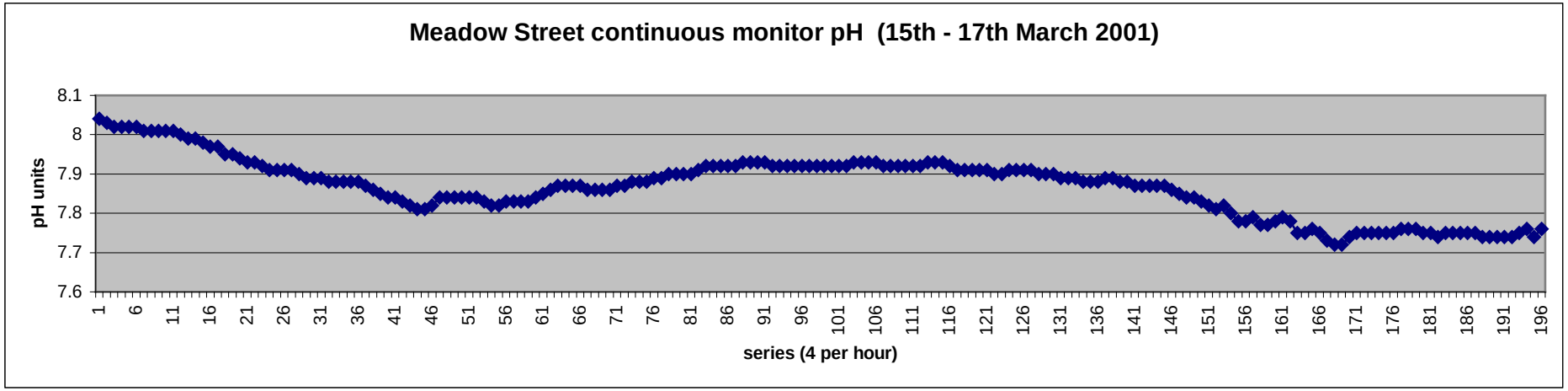
7.3e) Ammonia (N)



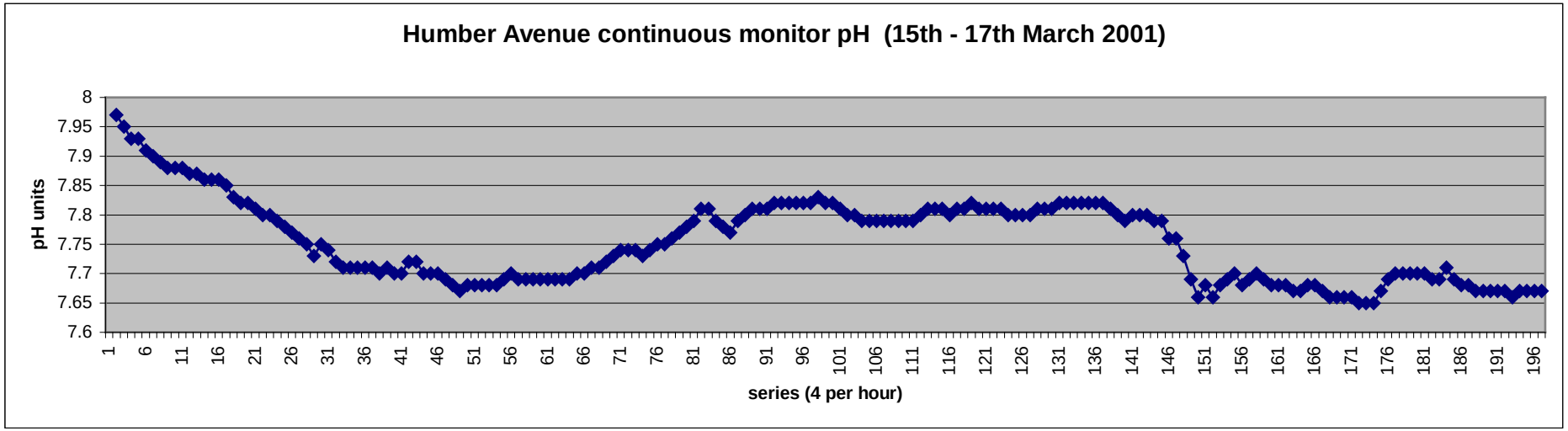
baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm



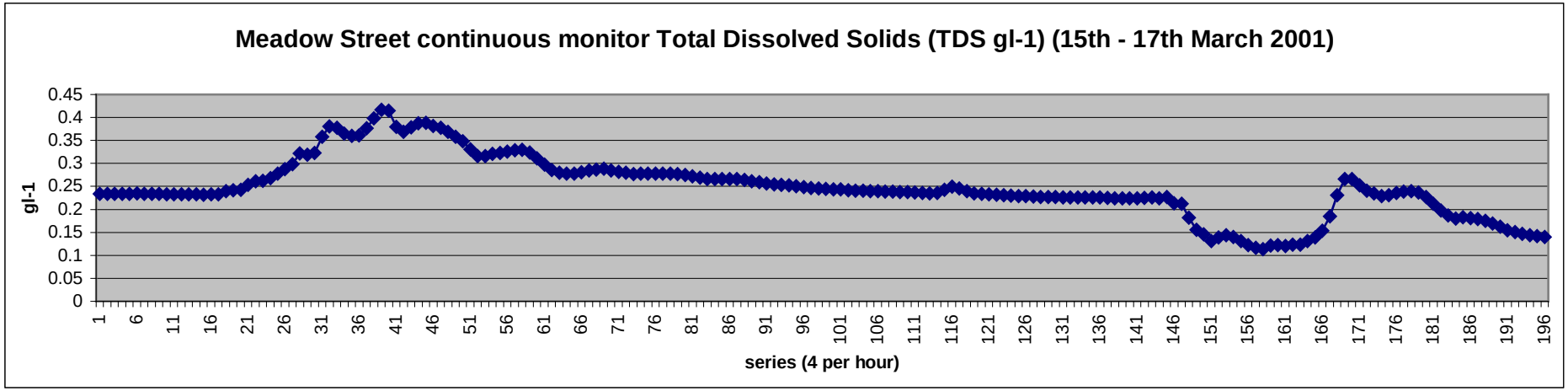
7.3f) pH



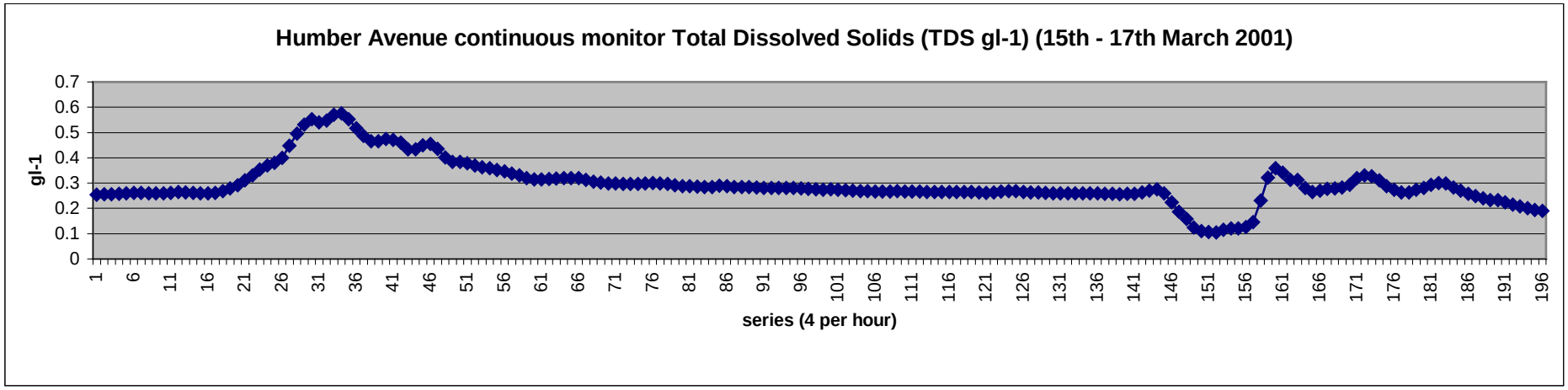
baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm



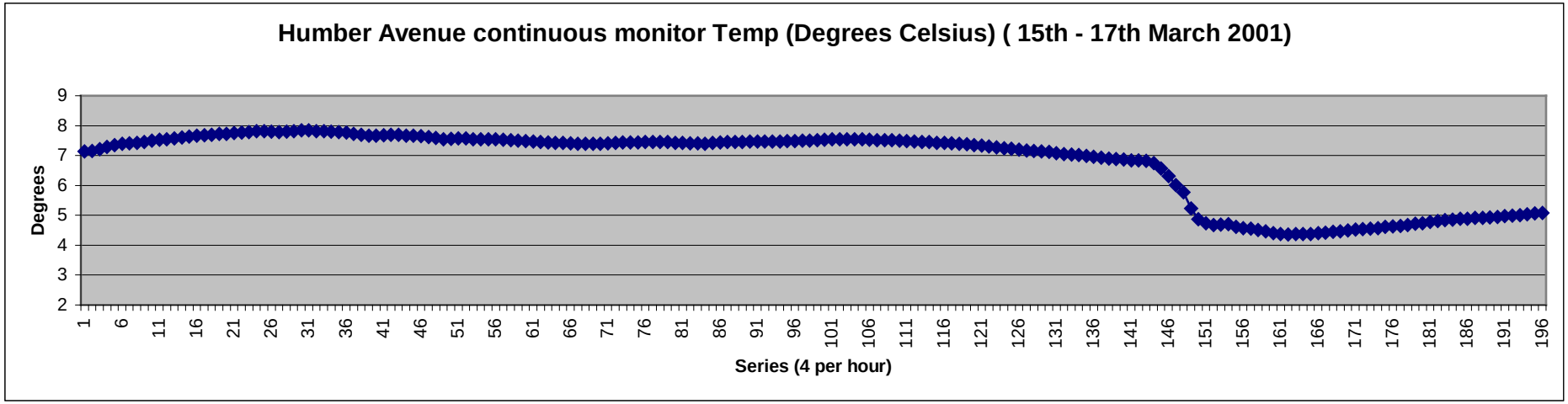
7.3g) Total Dissolved Solids



baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm



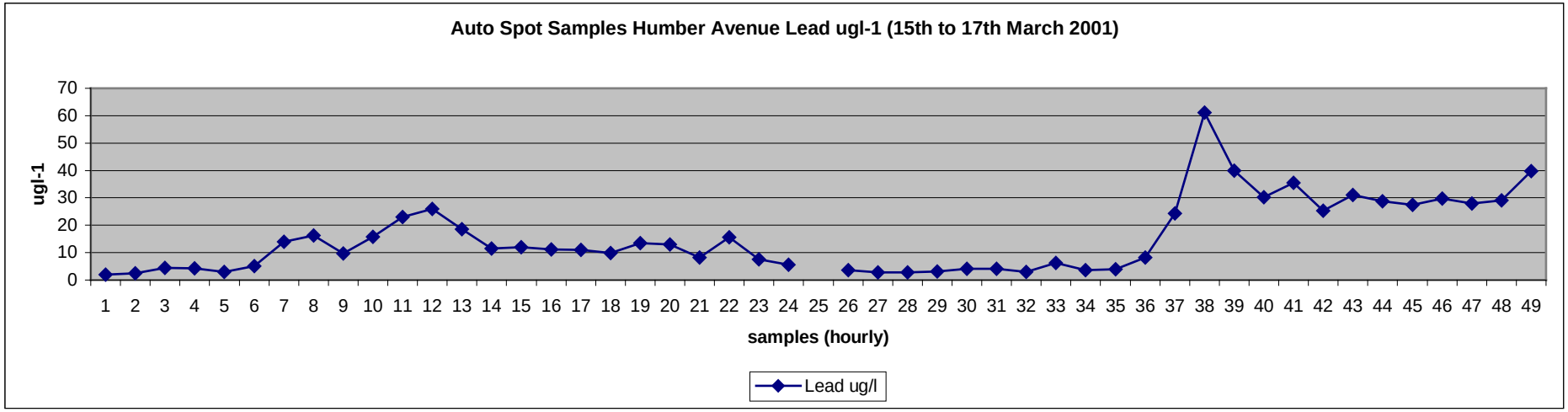
7.3h) Temperature



baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

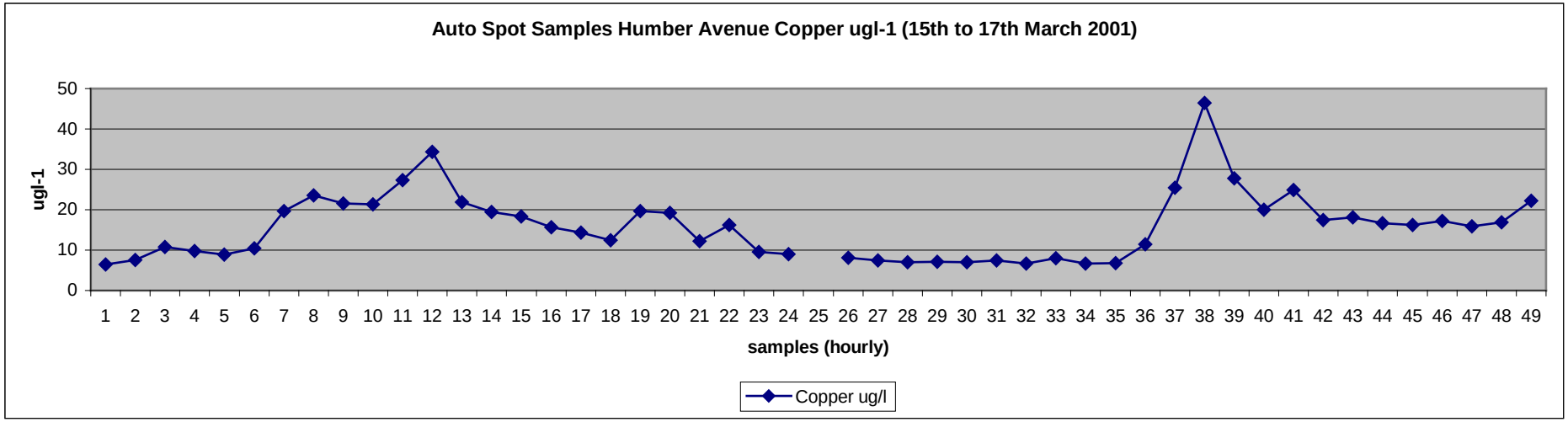
Figure 7.3: Auto Spot sampling results – Humber Avenue only

7.3i) Lead

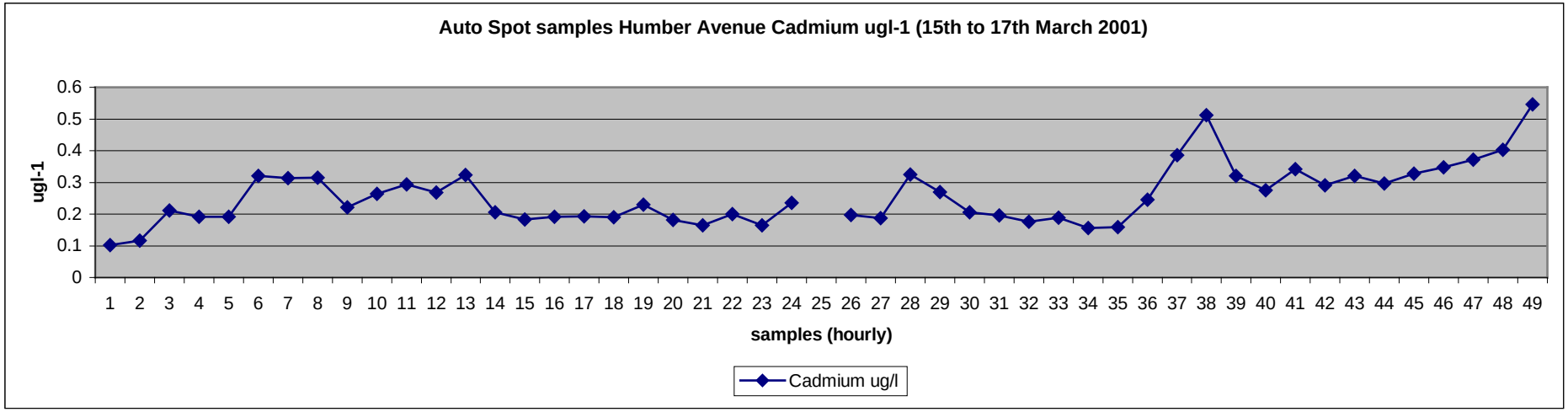


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

7.3j) Copper

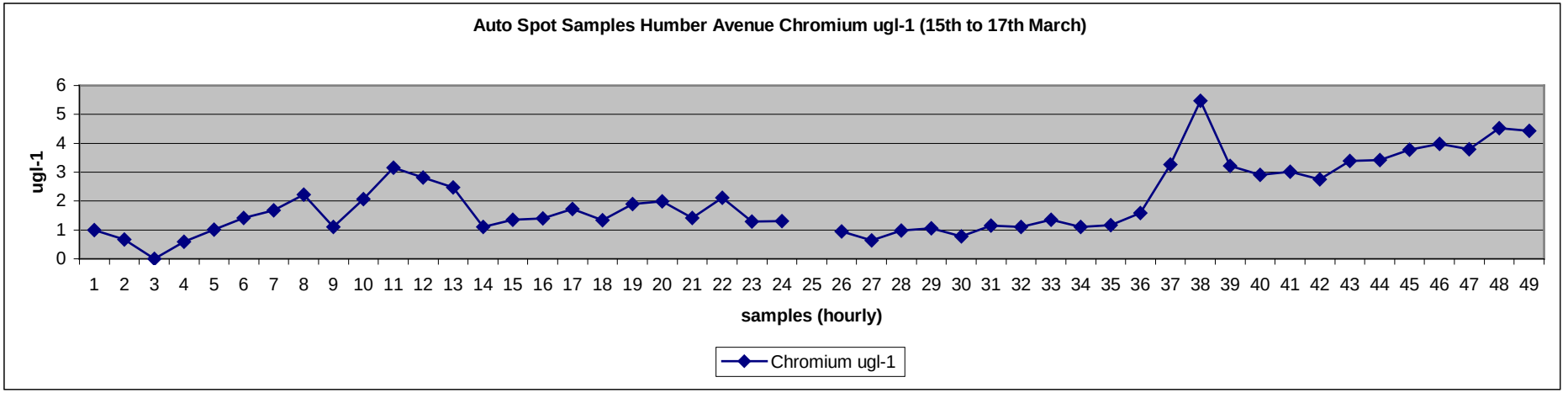


7.3k) Cadmium

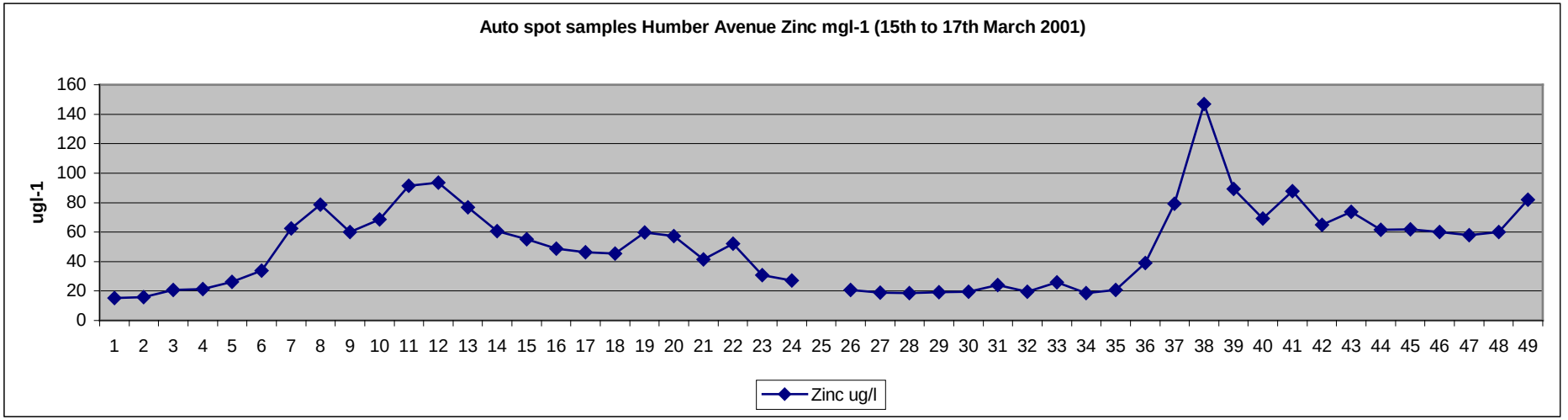


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2° peak rainfall period	post storm

7.3l) Chromium

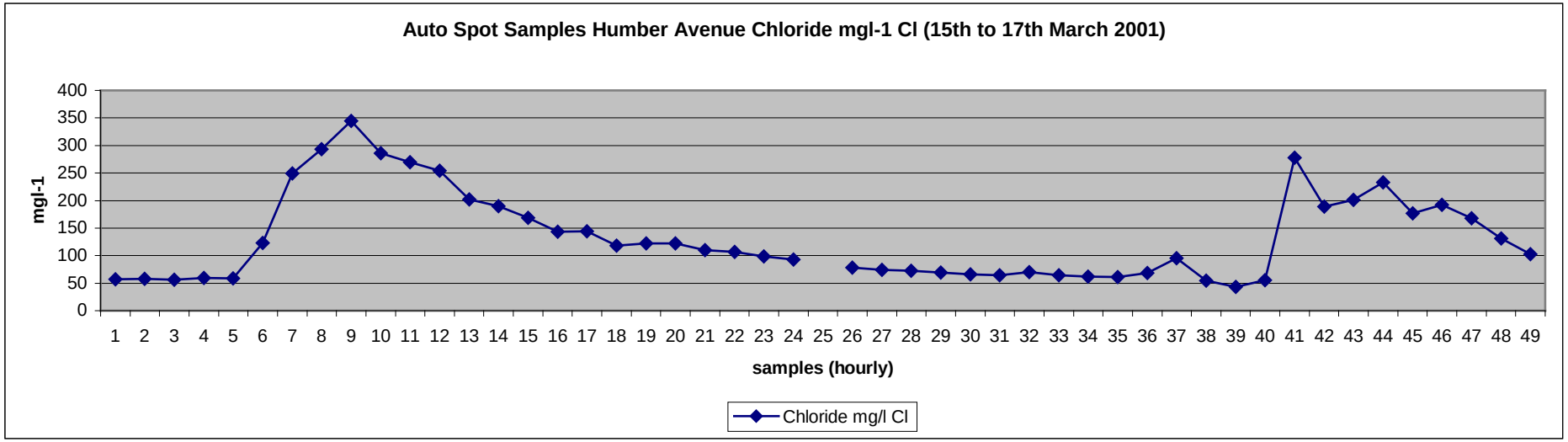


7.3m) Zinc

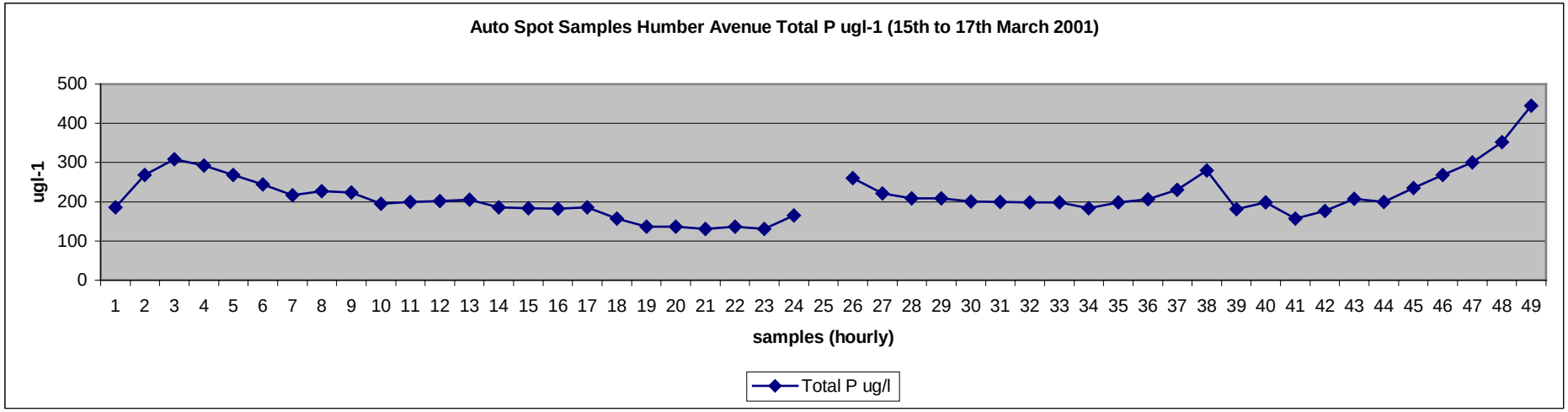


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2º peak rainfall period	post storm

7.3n) Chloride

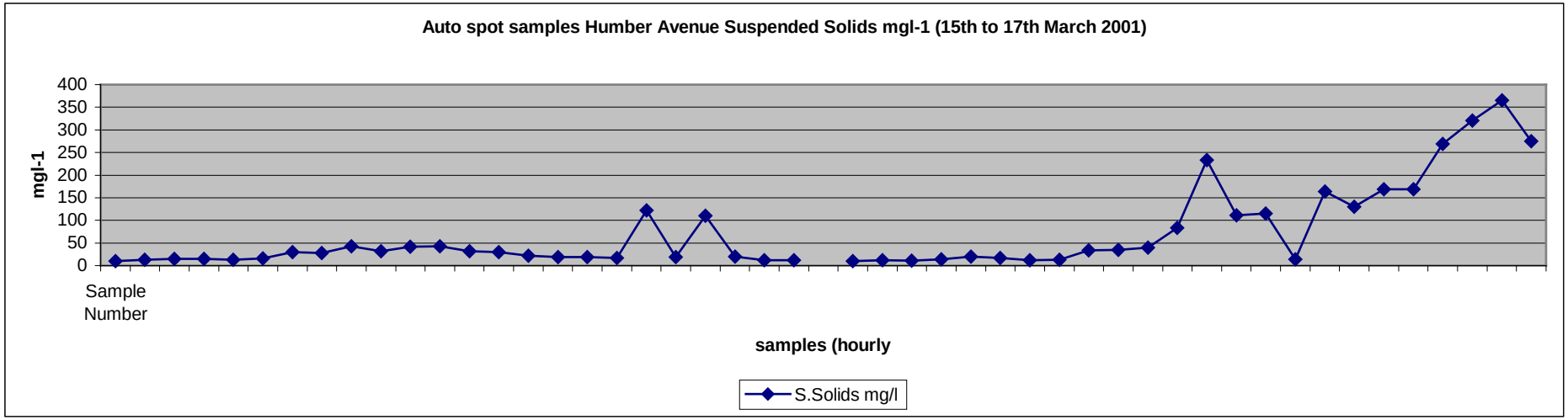


7.3o) Total P

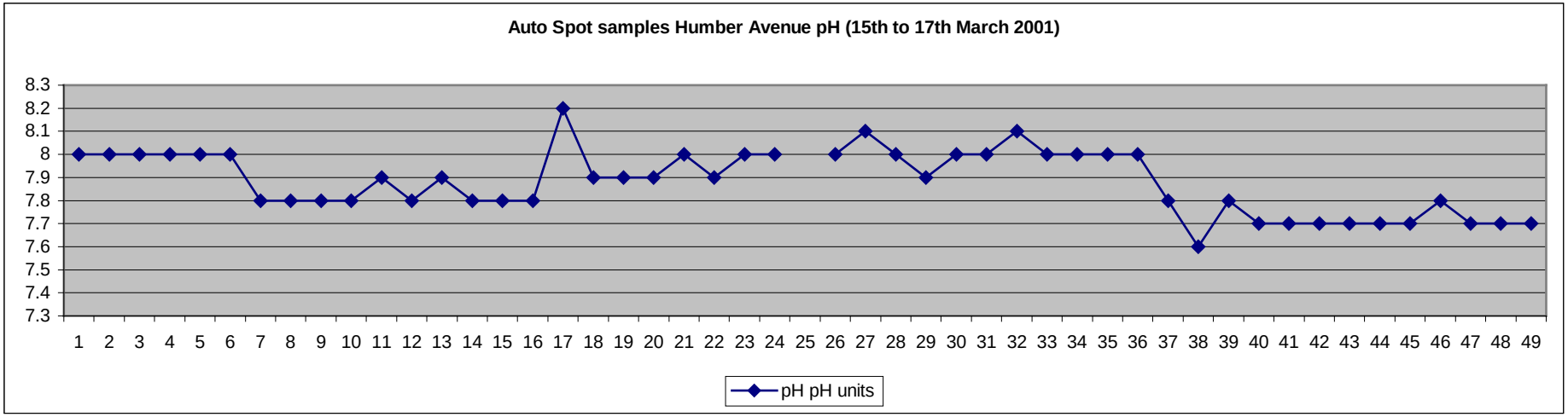


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2° peak rainfall period	post storm

7.3p) Suspended Solids

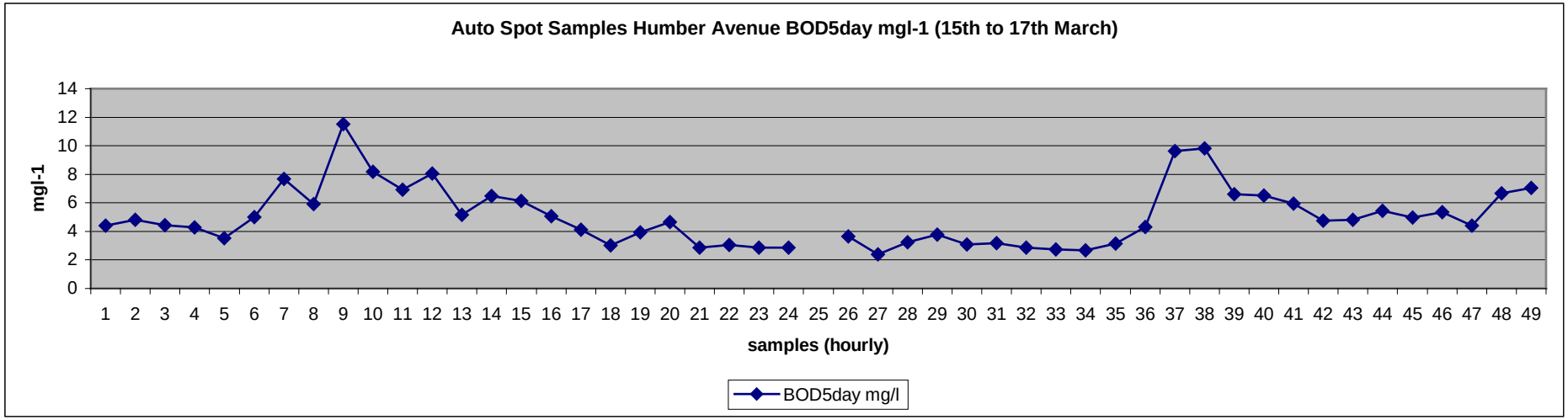


7.3q) pH

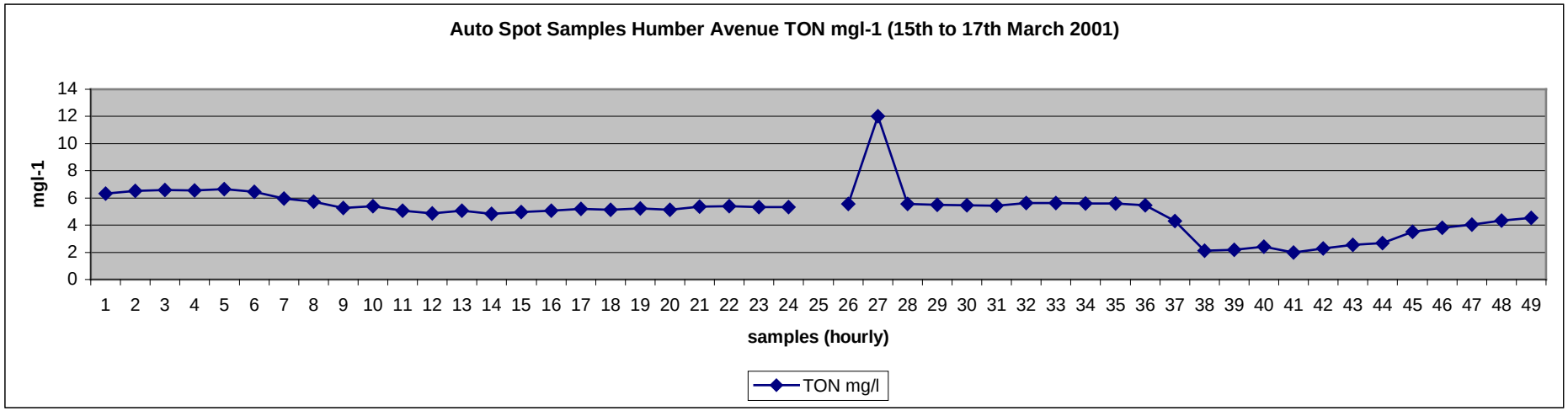


baseline period	initial rainfall period	pre-storm event	peak rainfall period	2° peak rainfall period	post storm

7.3r) Biochemical Oxygen Demand (BOD)



7.3s) Total Oxidised Nitrates (TON)



baseline period	initial rainfall period	pre-storm event	peak rainfall period	2° peak rainfall period	post storm

Appendix 8.1 Dry weather investigation September 2003 and Storm event November 2003

Figure a) Rainfall Dry weather event September 2003

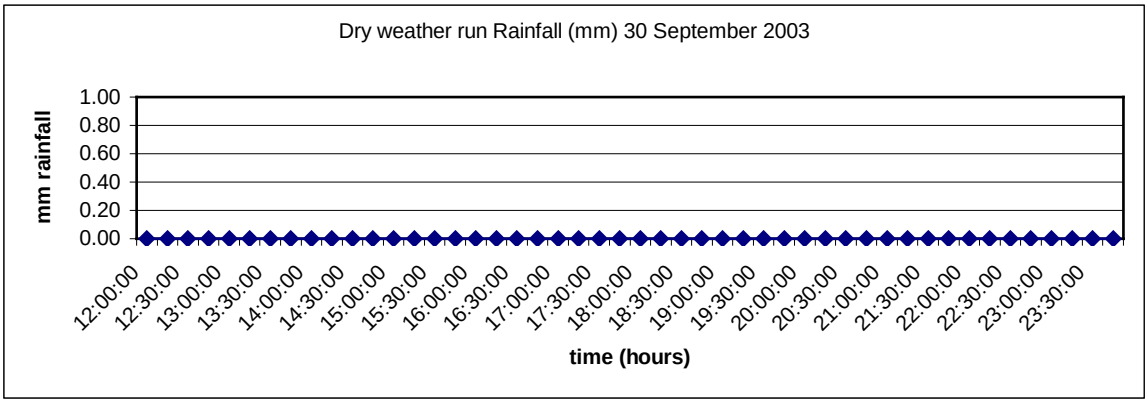


Figure b) River level Kingsbury Avenue September 2003

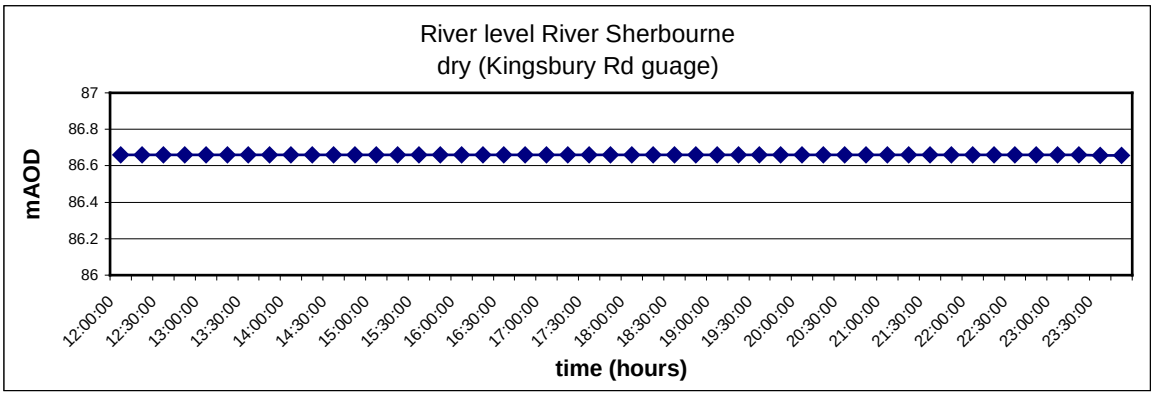


Figure c) Continuous monitoring– BOD and TON September 2003

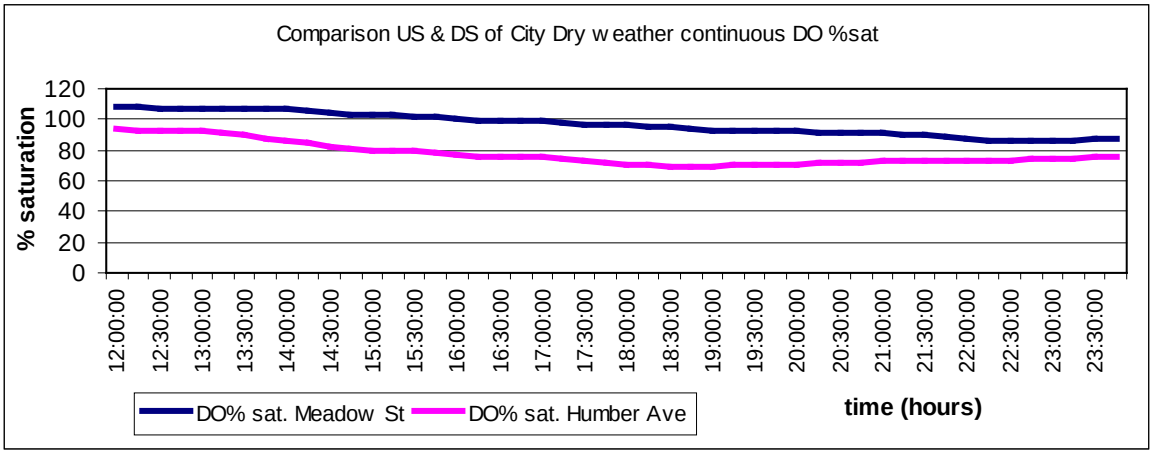


Figure d) Continuous monitoring– ammonium both sites September 2003

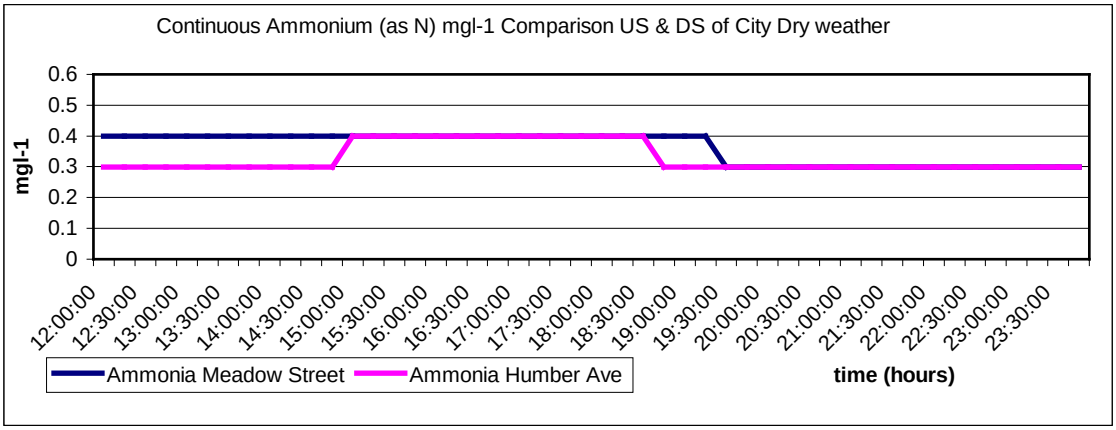


Figure e) Continuous monitoring– pH both sites September 2003

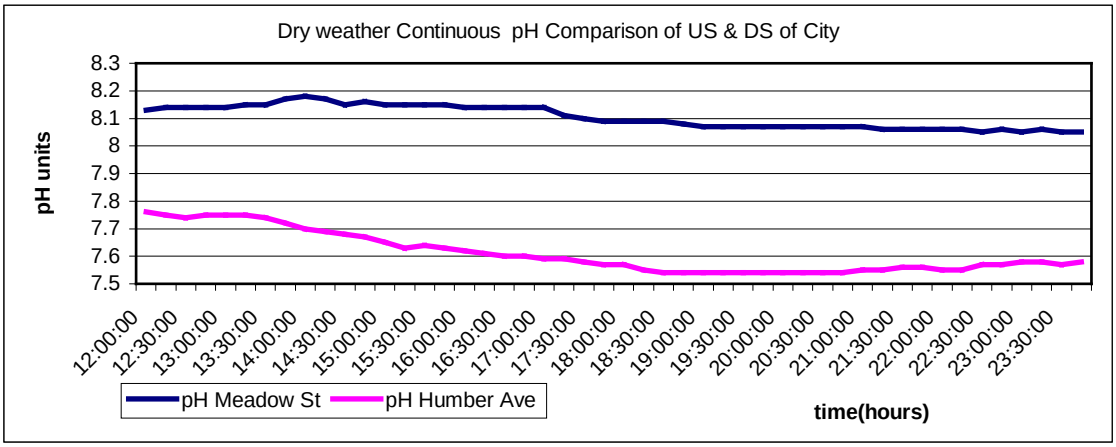


Figure f) Continuous monitoring– Specific conductivity both sites September 2003

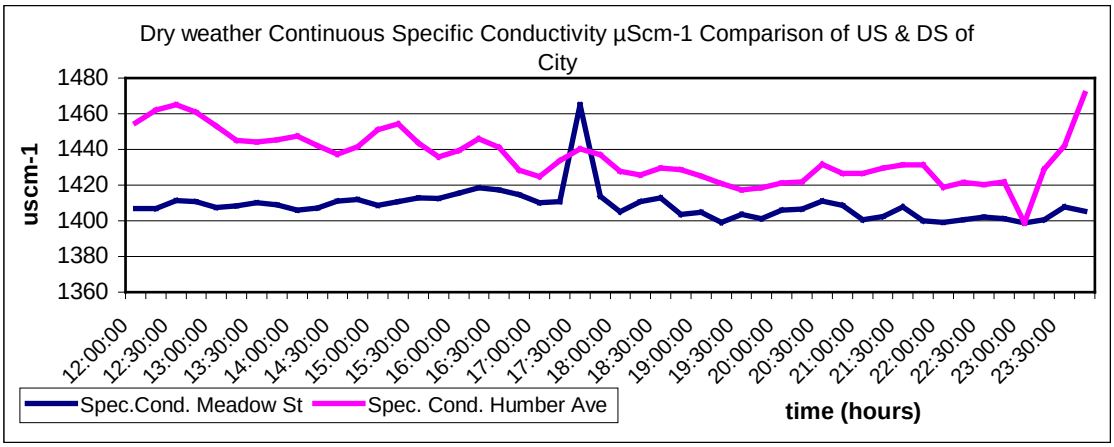


Figure g) Continuous monitoring–Temperature Upstream and downstream of City September 2003

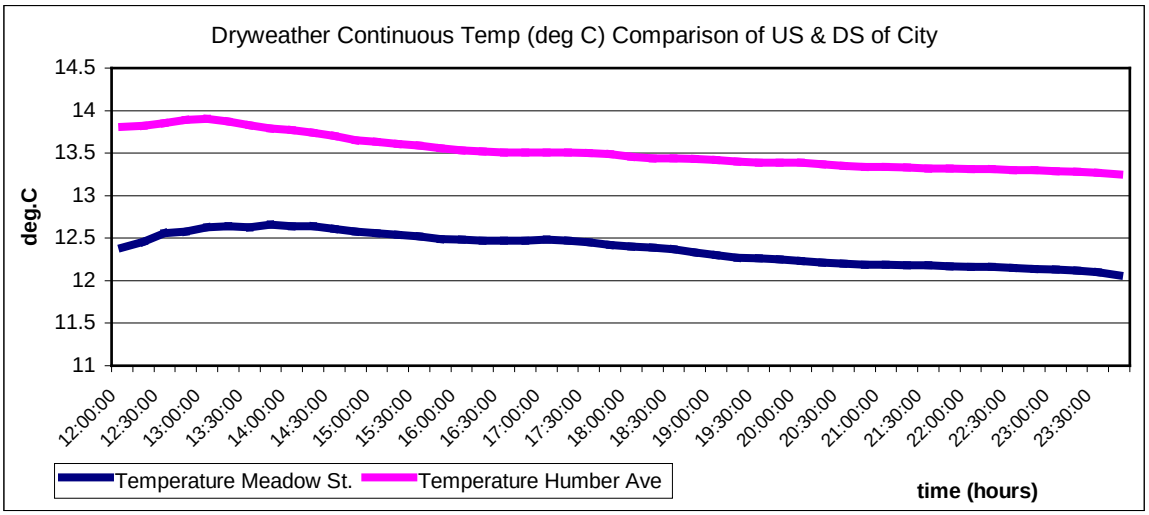


Figure h) Auto-sample –Zinc concentrations Upstream and downstream of City September 2003

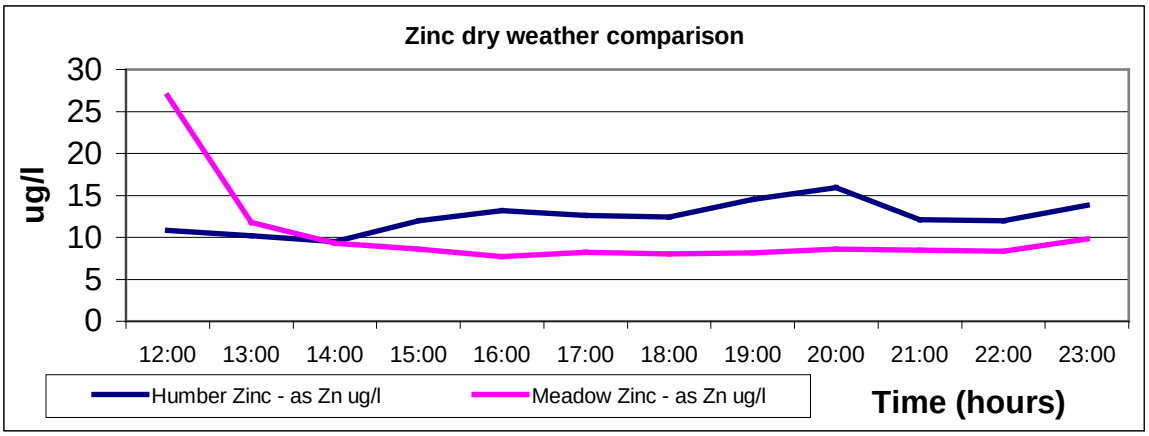


Figure i) Auto-sample –Cu concentration Upstream and downstream of City September 2003

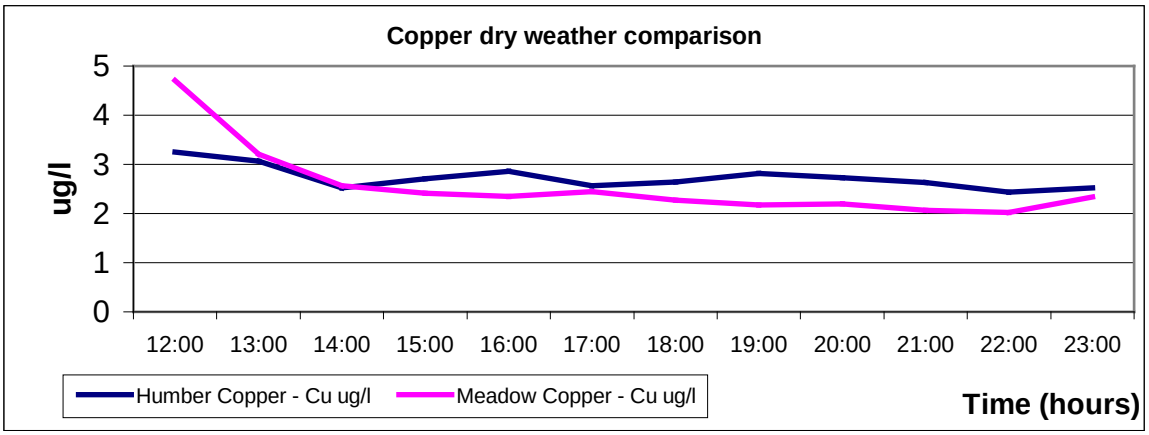


Figure j) Auto-sample –Lead concentrations Upstream and downstream of City September 2003

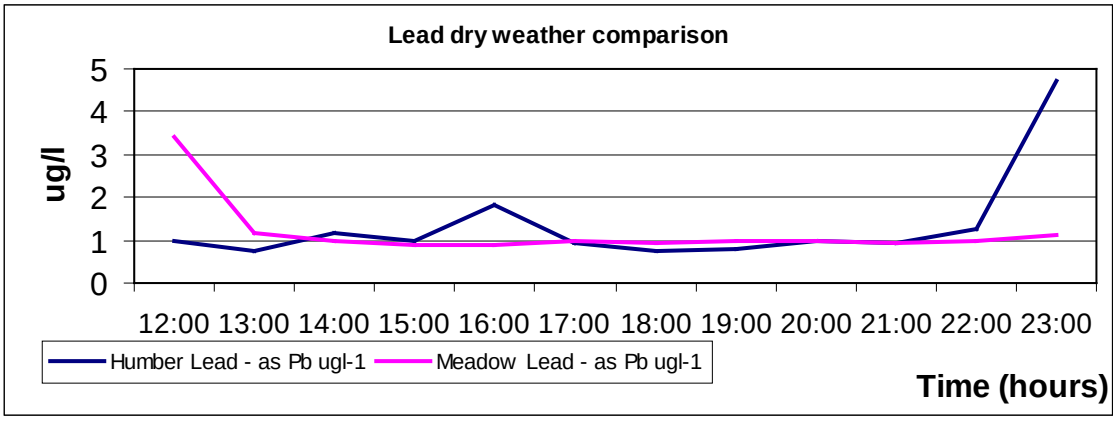


Figure k) Auto-sample–Cr concentration Upstream and downstream of City September 2003

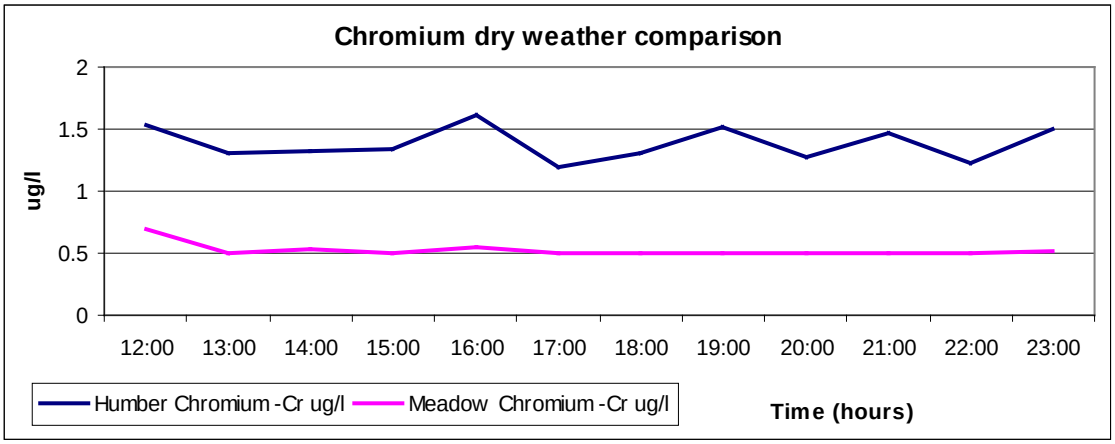


Figure l) Auto-sample–Suspended Solids concentration Upstream and downstream of City September 2003

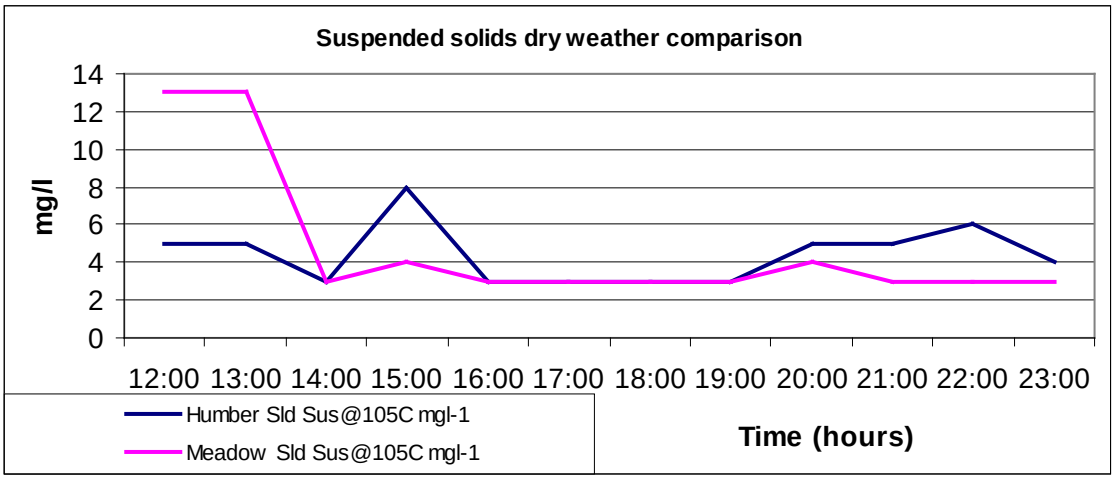


Figure m) Auto-sample–pH measurement Upstream and downstream of City September 2003

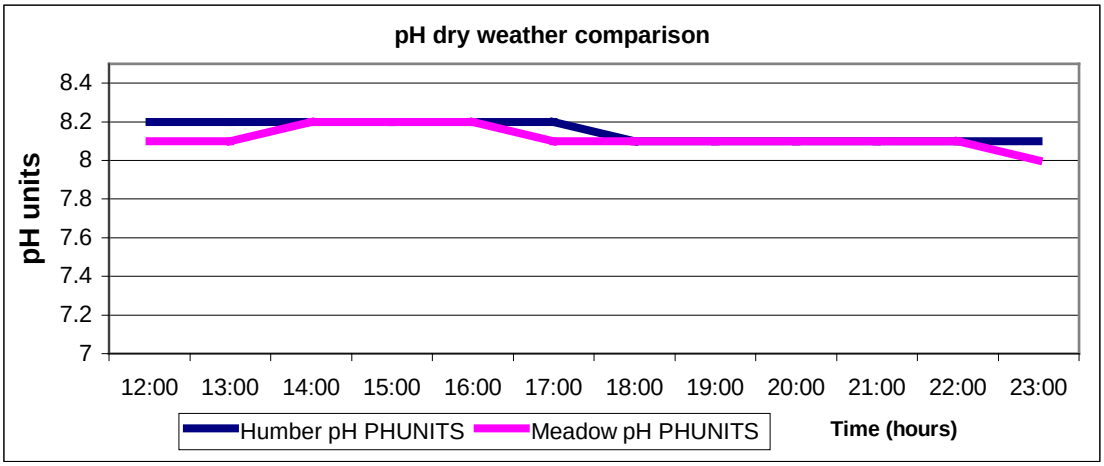


Figure n) Auto-sample– BOD Upstream and downstream of City September 2003

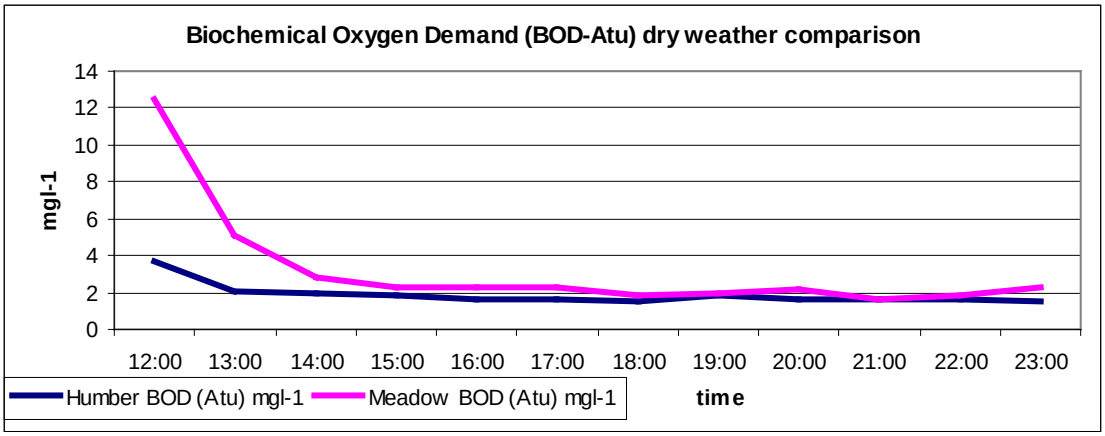


Figure o) Auto-sample–TON measurement Upstream and downstream of City September 2003

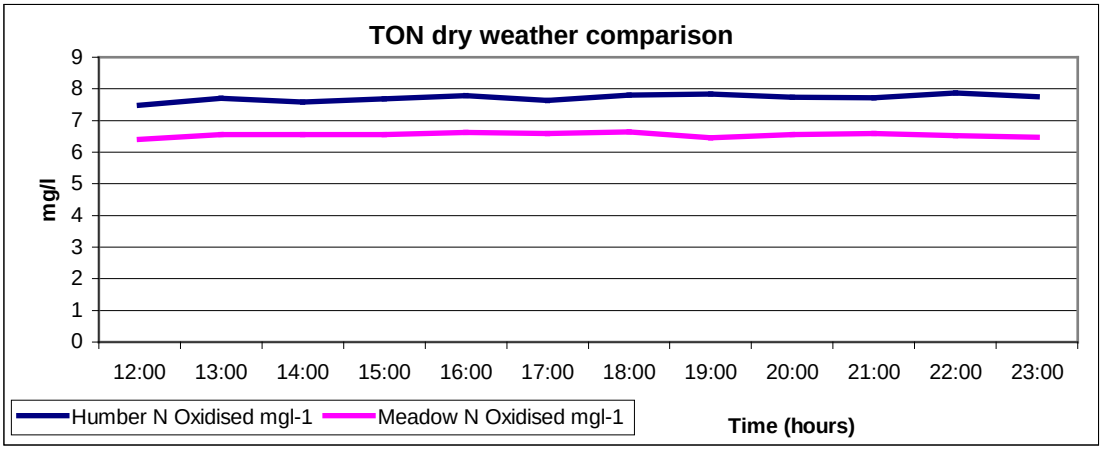
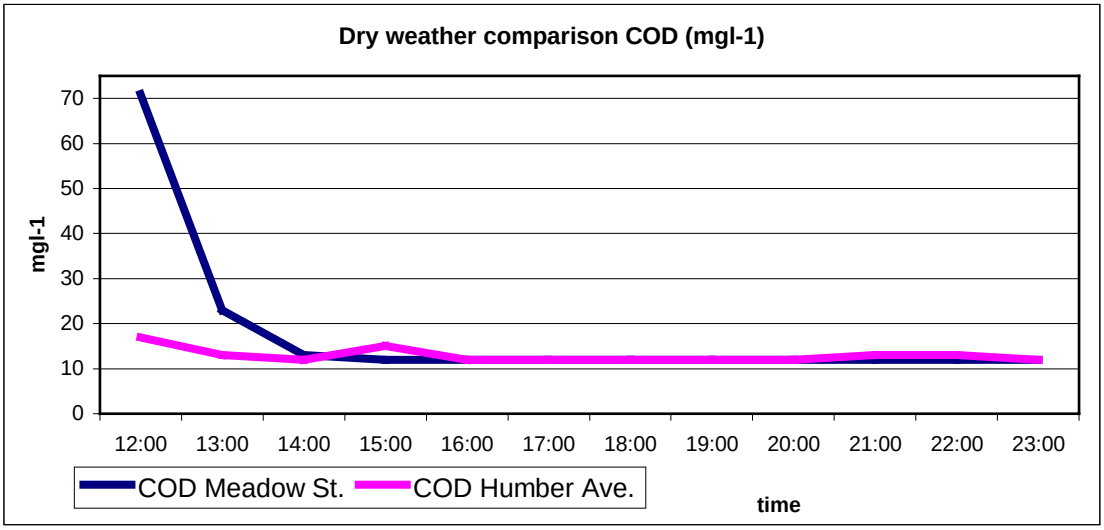
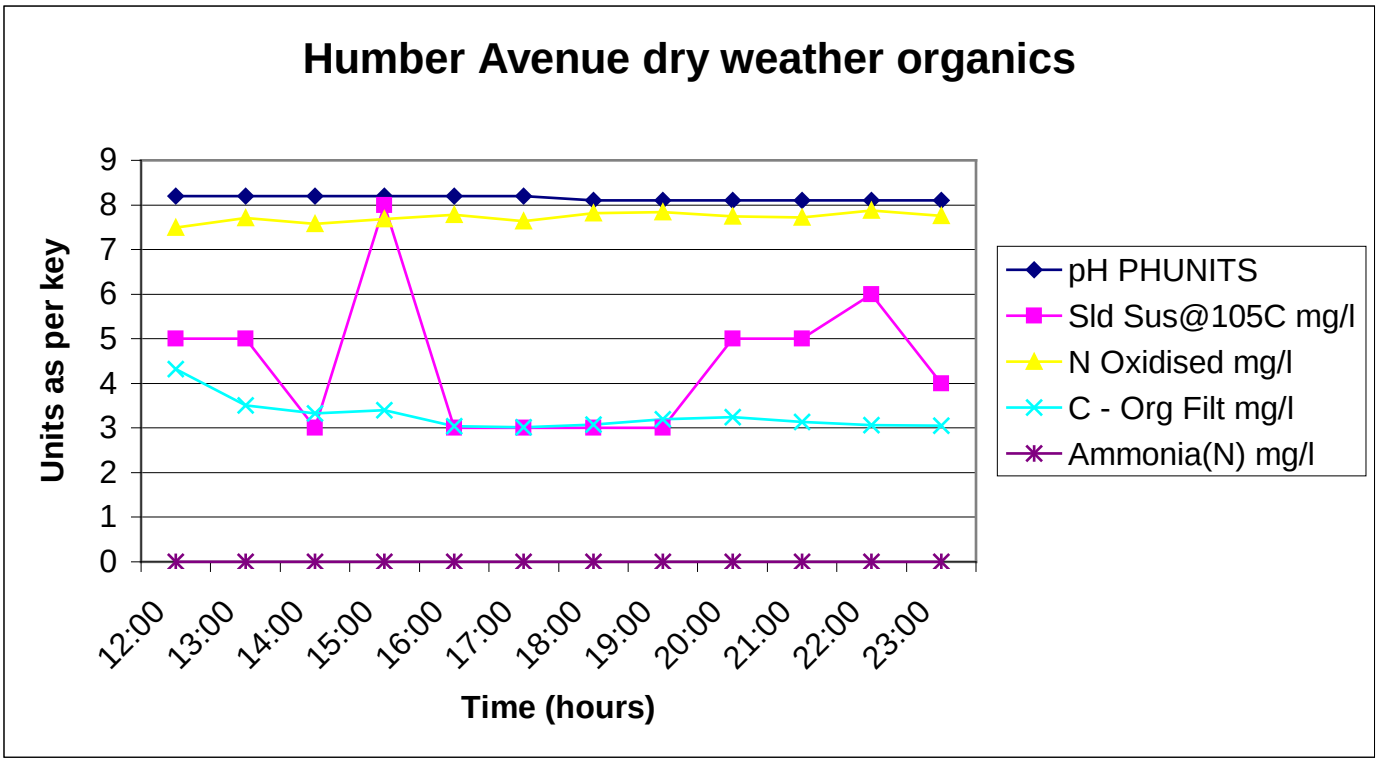
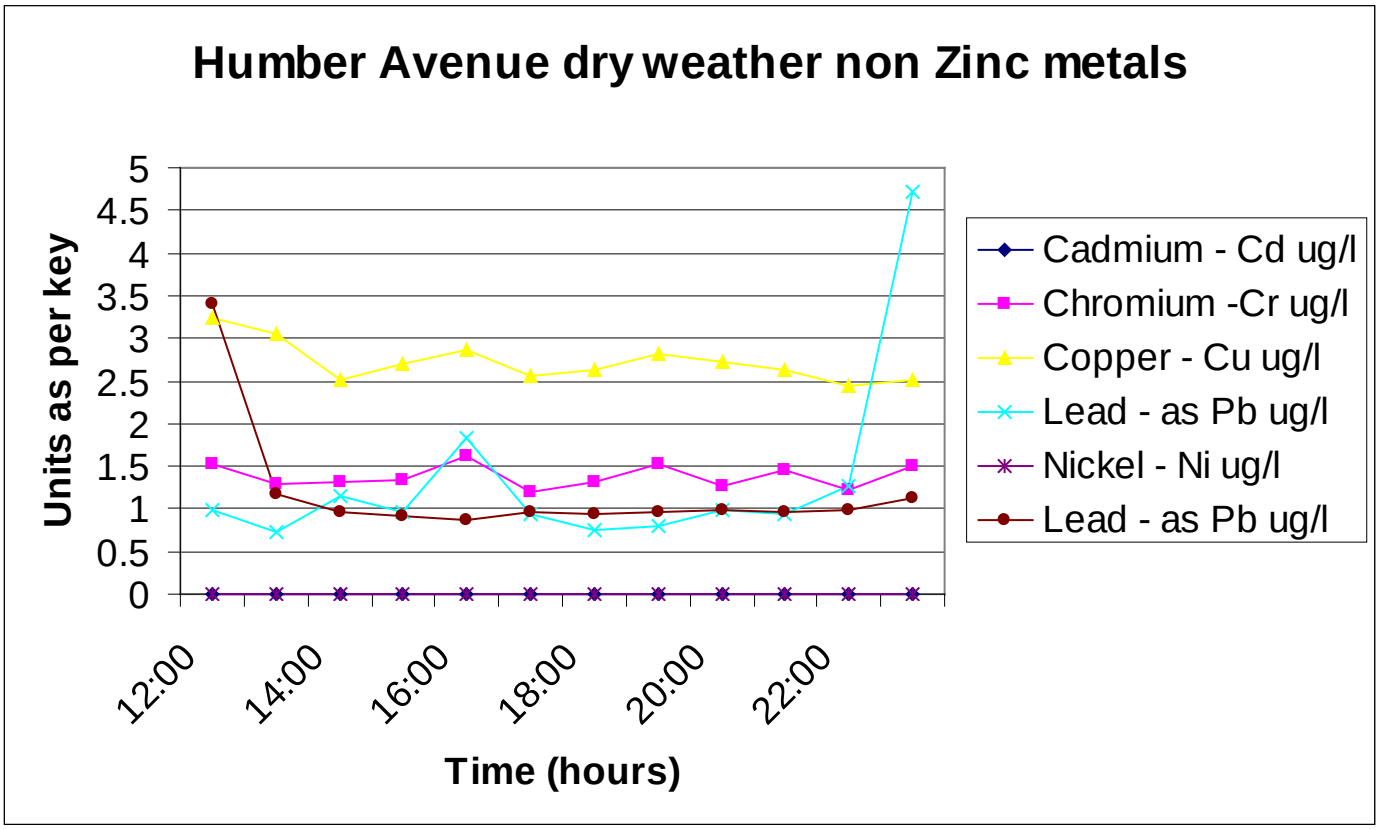
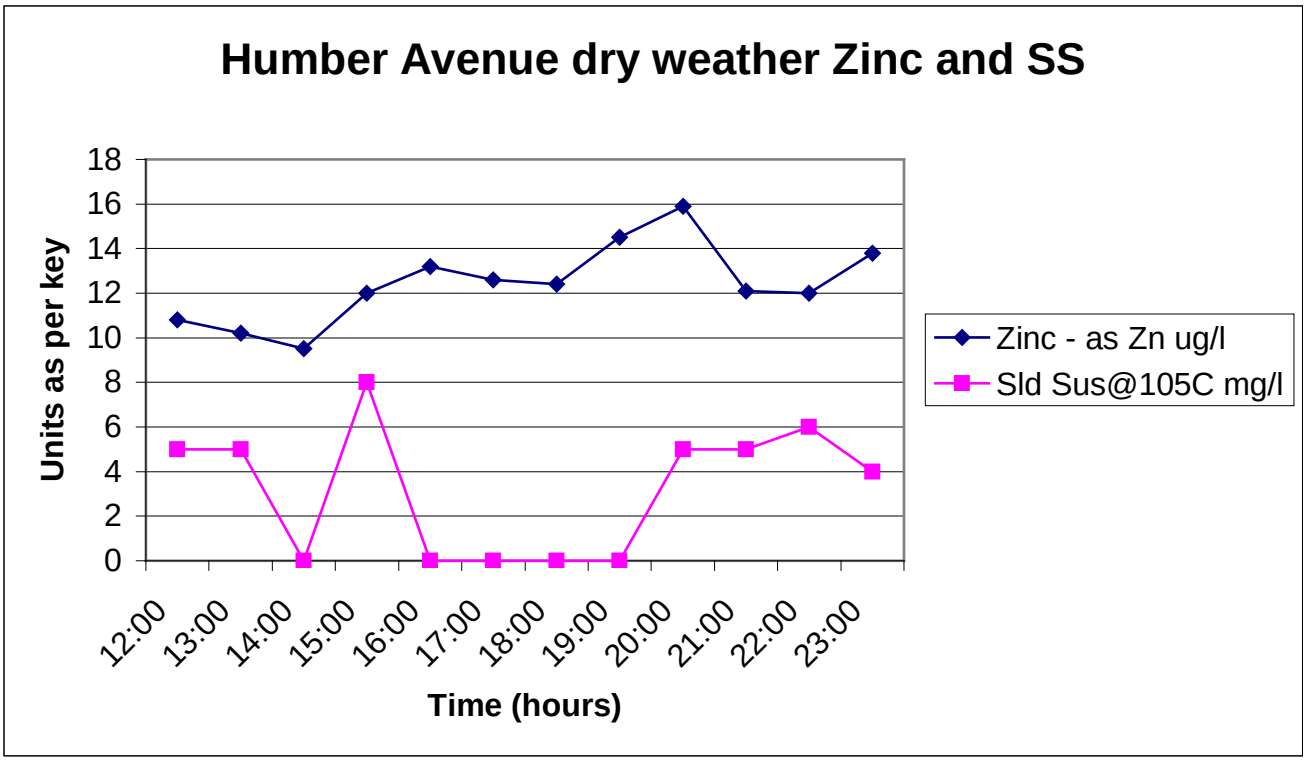


Figure p) Auto-sample–COD measurement Upstream and downstream of City September 2003

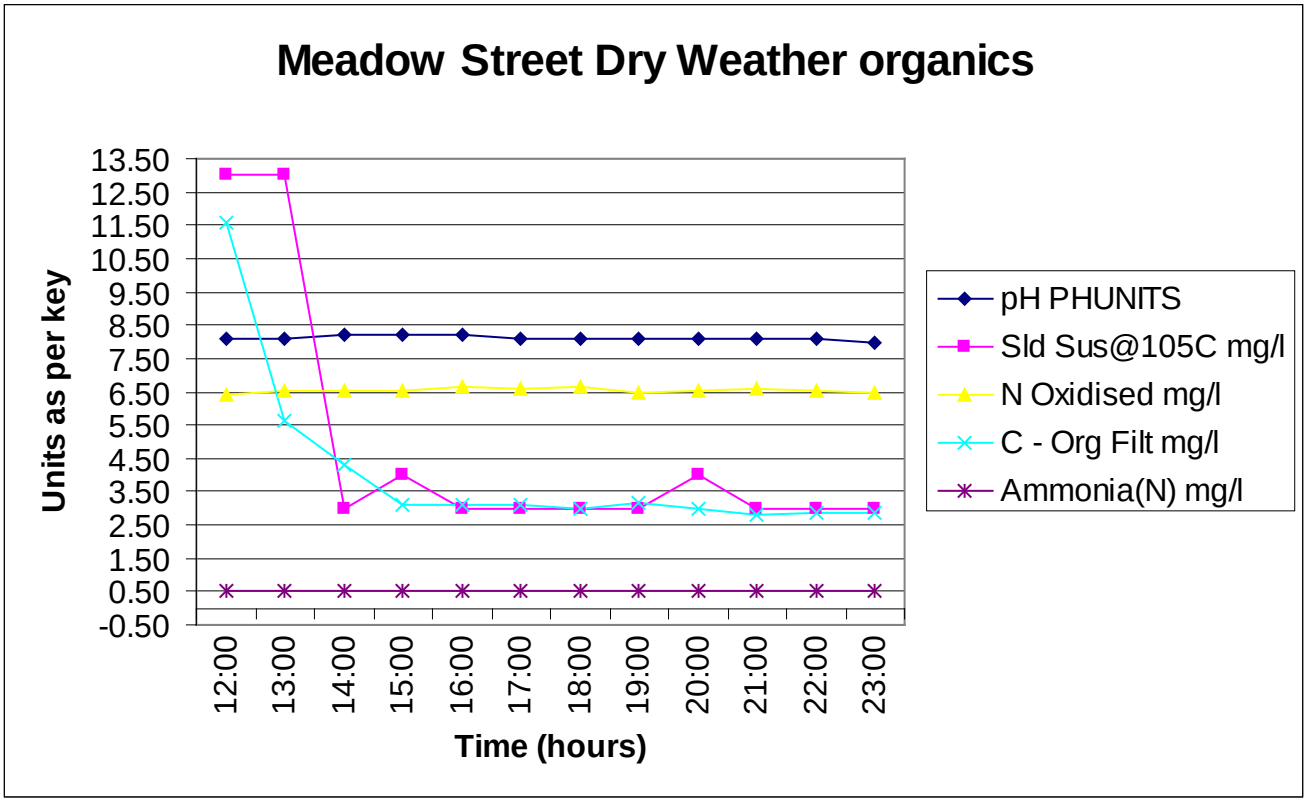



Humber Avenue dry weather organics
Units as per key
0
1
2
3
4
5
6
7
8
9
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time (hours)
pH PHUNITS
Sld Sus@105C mg/l
N Oxidised mg/l
C - Org Filt mg/l
Ammonia(N) mg/l

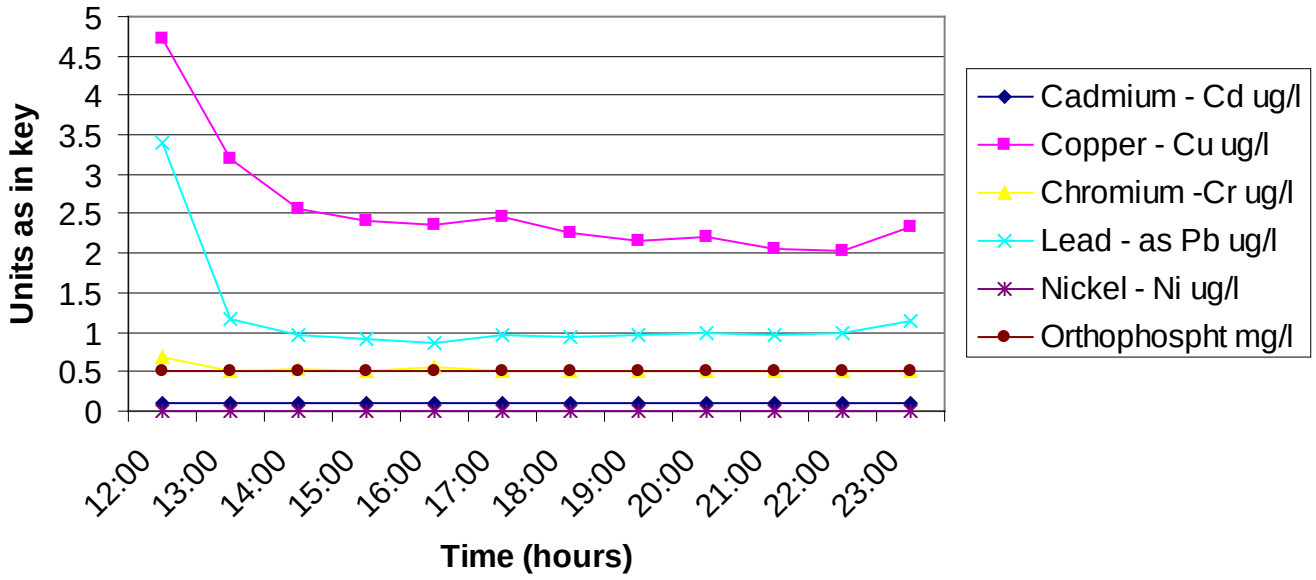

Humber Avenue dry weather non Zinc metals
Units as per key
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
12:00
14:00
16:00
18:00
20:00
22:00
Time (hours)
Cadmium - Cd ug/l
Chromium -Cr ug/l
Copper - Cu ug/l
Lead - as Pb ug/l
Nickel - Ni ug/l
Lead - as Pb ug/l



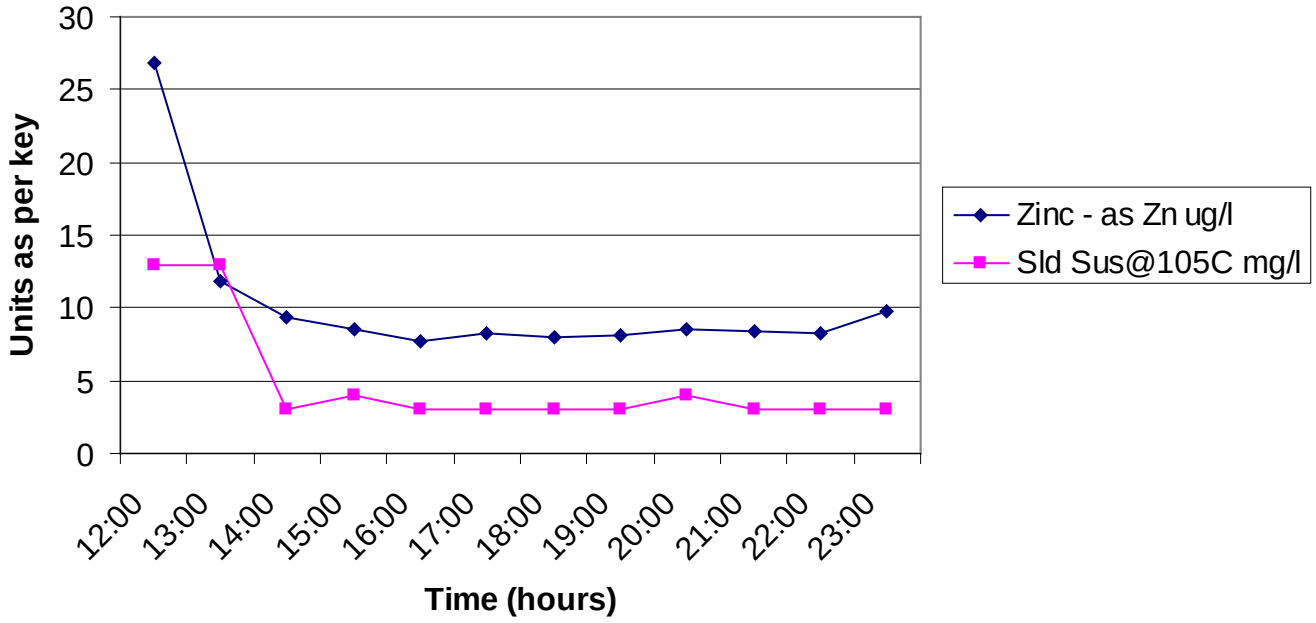
Meadow St Dry weather Investigation September 2003 samples

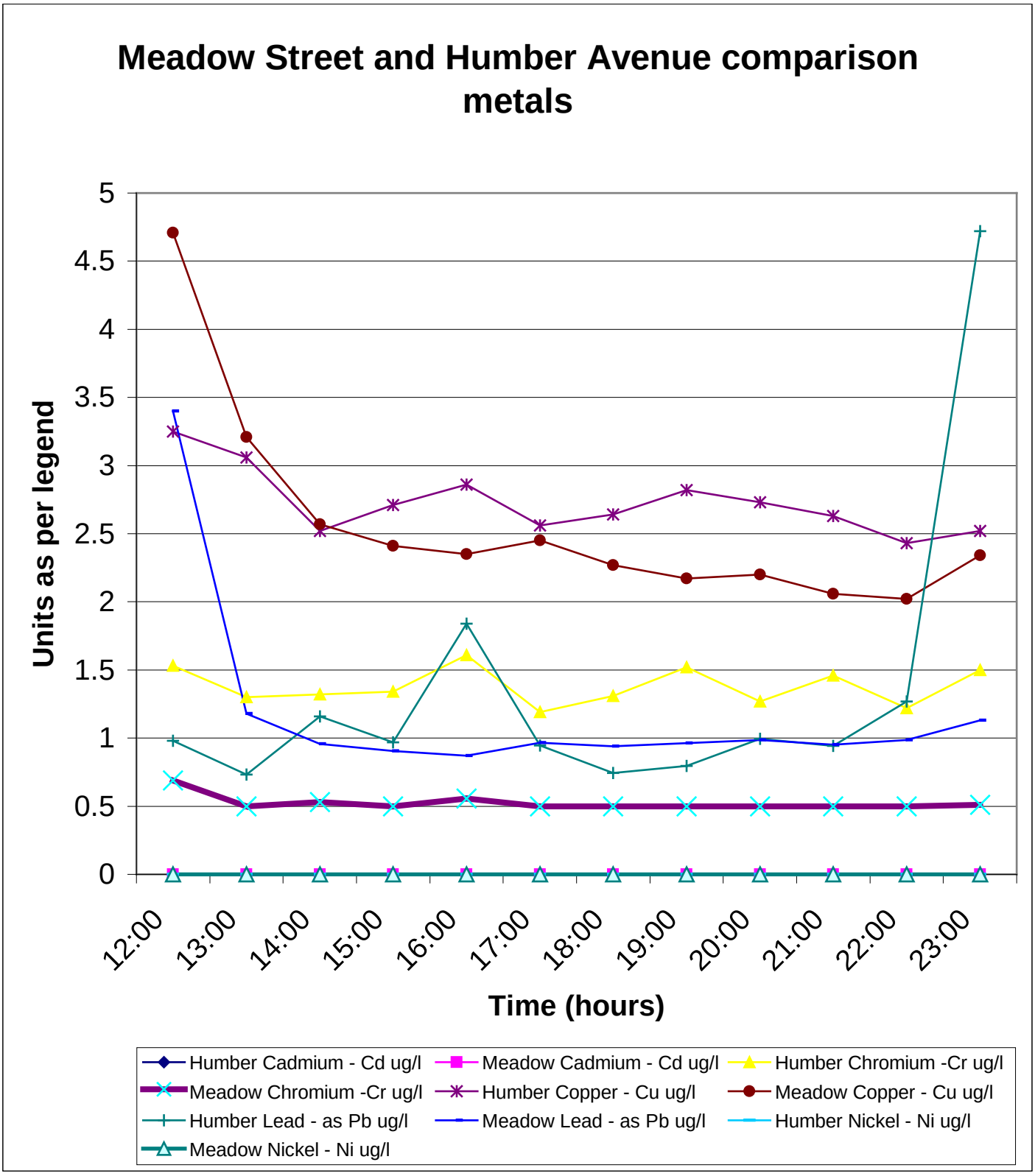


Meadow Street dry weather non- Zinc metals and phosphate



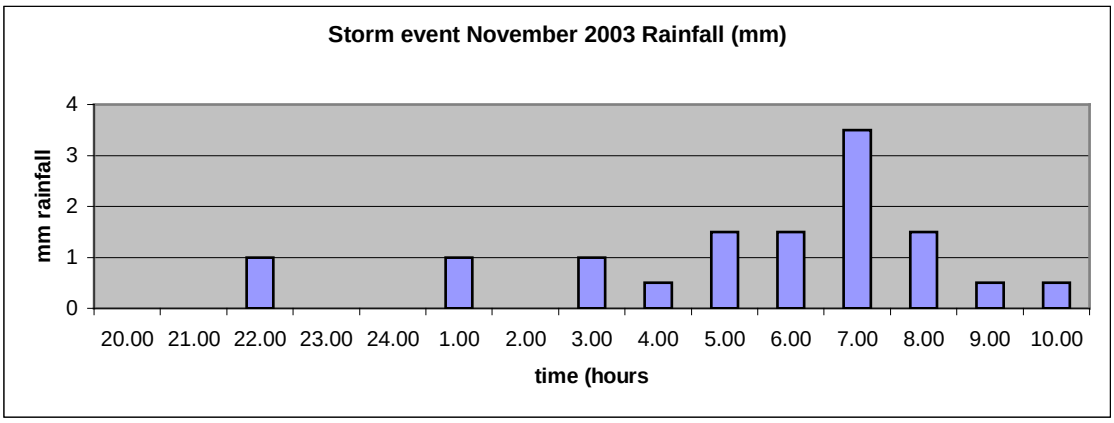
Meadow Sreet dry weather Zinc and SS




Meadow Street and Humber Avenue comparison metals
Units as per legend
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time (hours)
Humber Cadmium - Cd ug/l
Meadow Cadmium - Cd ug/l
Humber Chromium -Cr ug/l
Meadow Chromium -Cr ug/l
Humber Copper - Cu ug/l
Meadow Copper - Cu ug/l
Humber Lead - as Pb ug/l
Meadow Lead - as Pb ug/l
Humber Nickel - Ni ug/l
Meadow Nickel - Ni ug/l

Appendix 9.1 Storm event November 2003

Figure a) Rainfall



Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure b) River Depth US of City

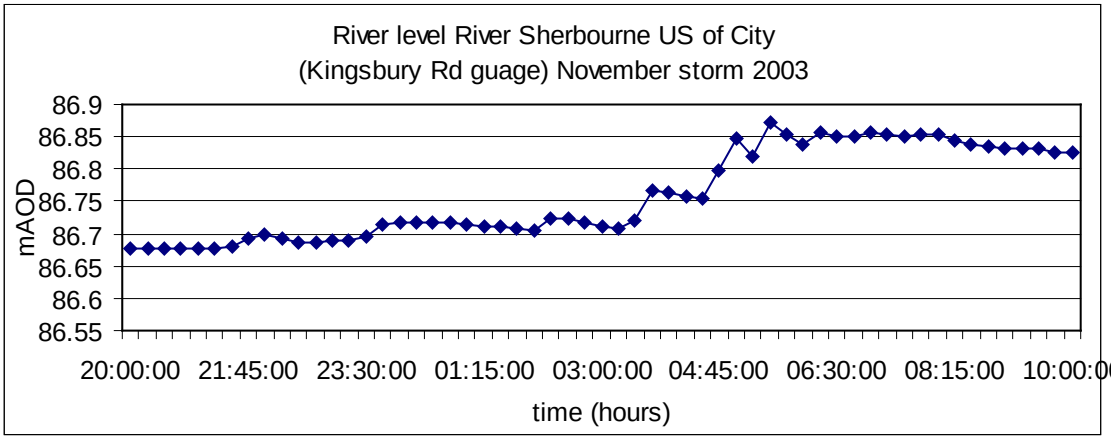


Figure c) River Depth DS of City

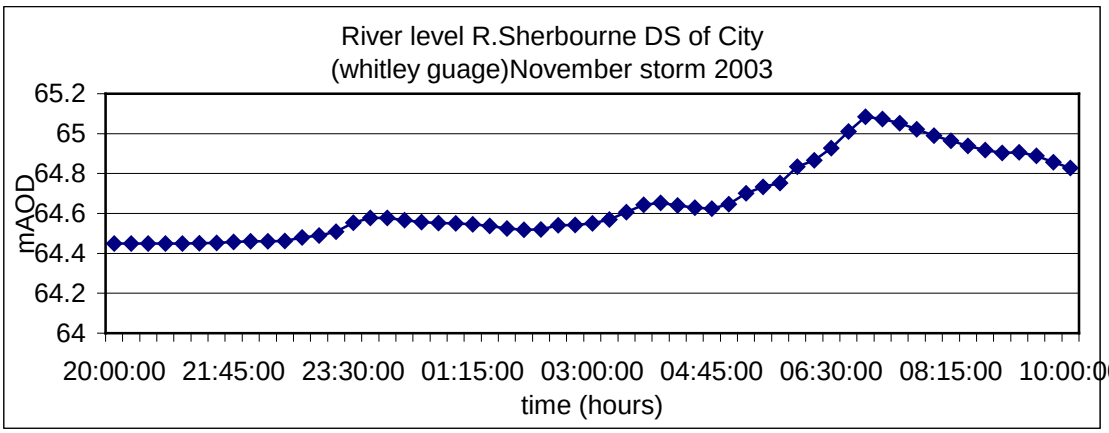
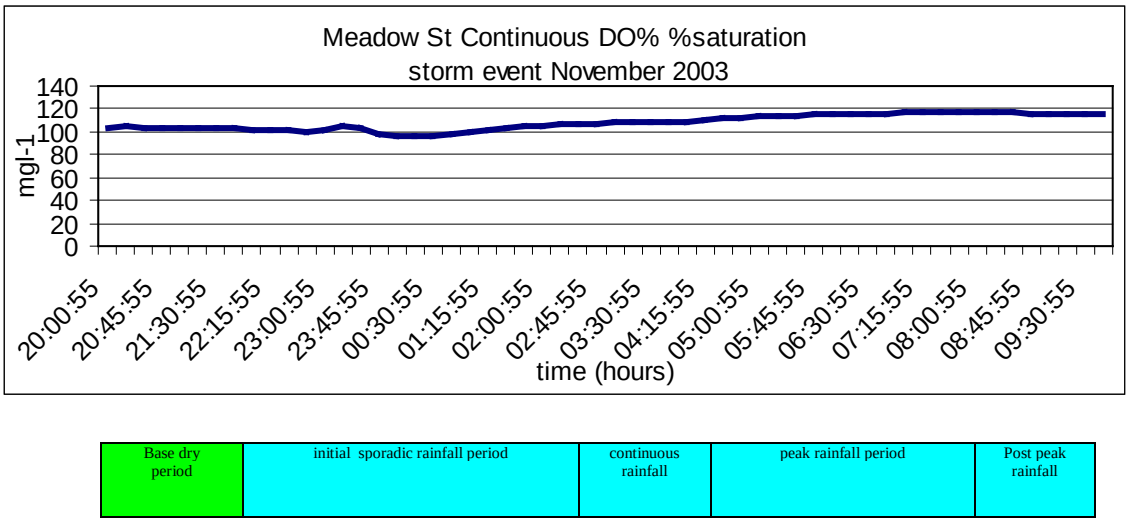
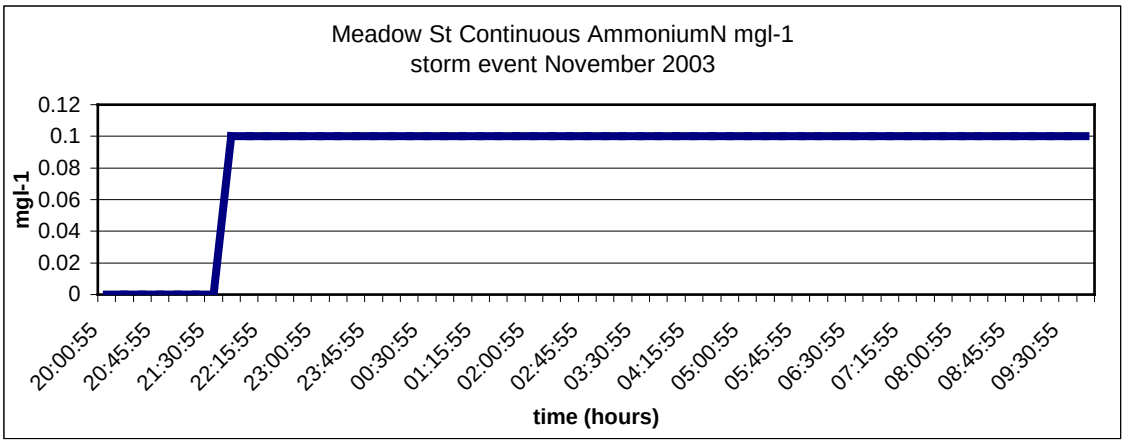


Figure d) Continuous D.O., storm event November 2003



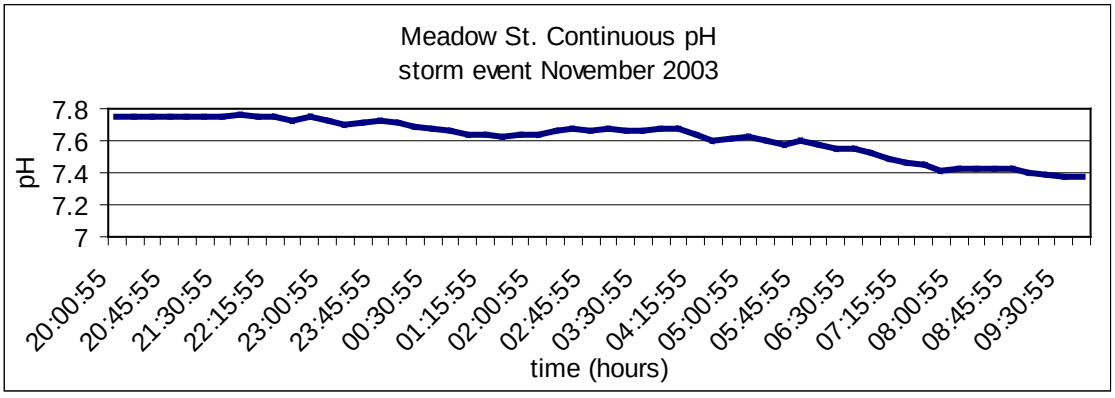
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure e) Continuous ammonium storm event November 2003



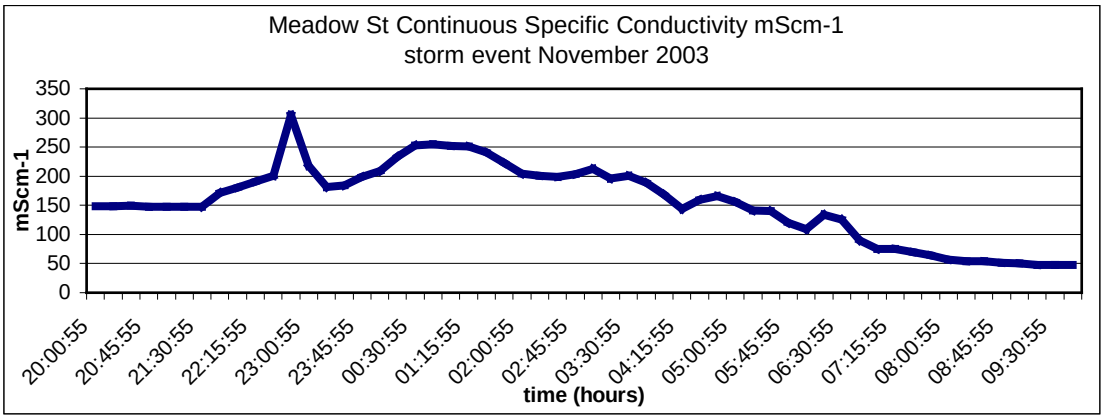
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure f) Continuous pH storm event November 2003



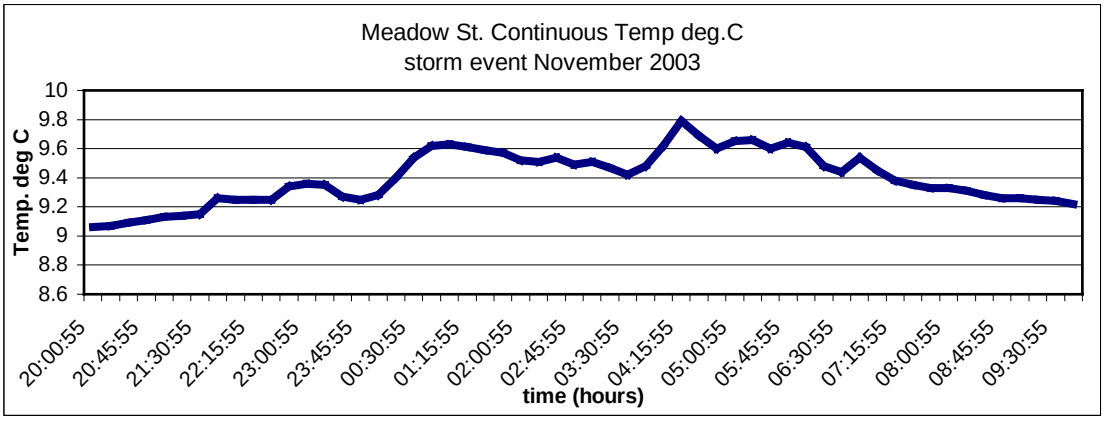
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure g) Continuous specific conductivity storm event November 2003



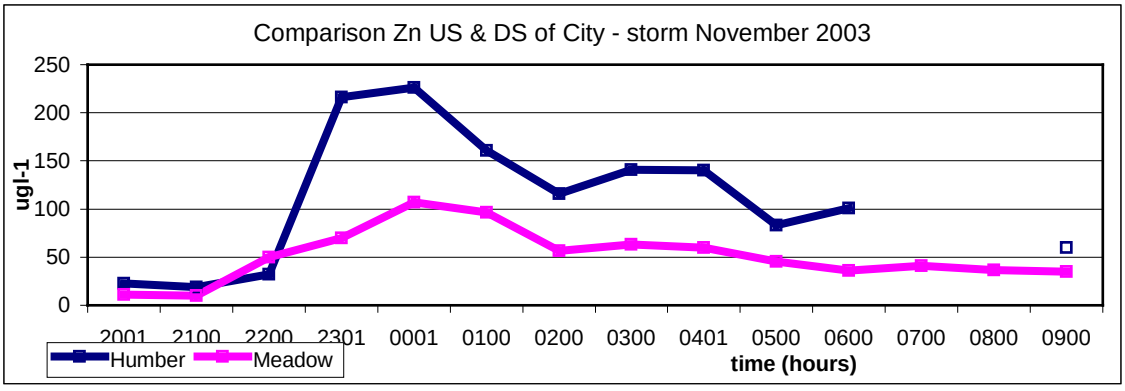
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure h) Continuous temperature storm event November 2003



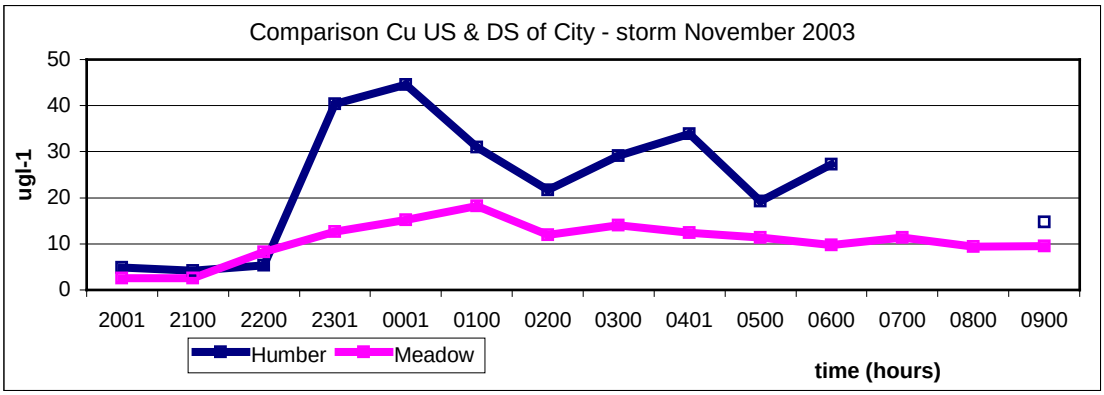
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure i) Sampled Zinc comparisons storm event November 2003



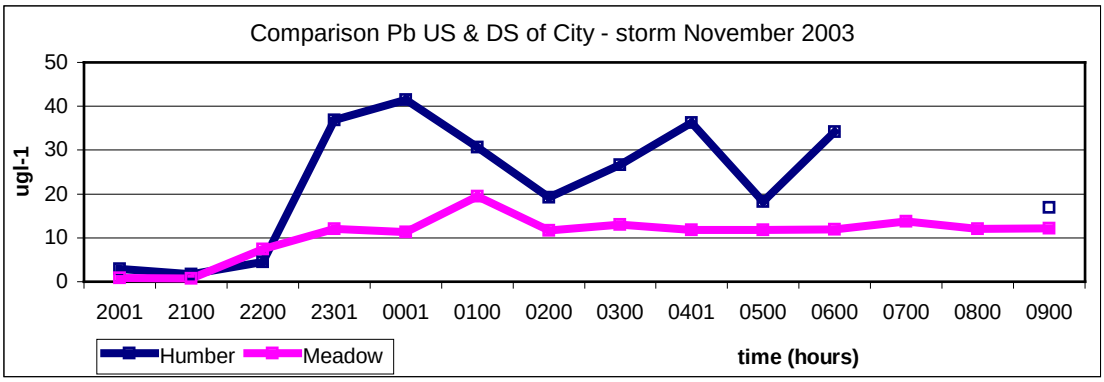
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure j) Sampled Copper comparisons storm event November 2003



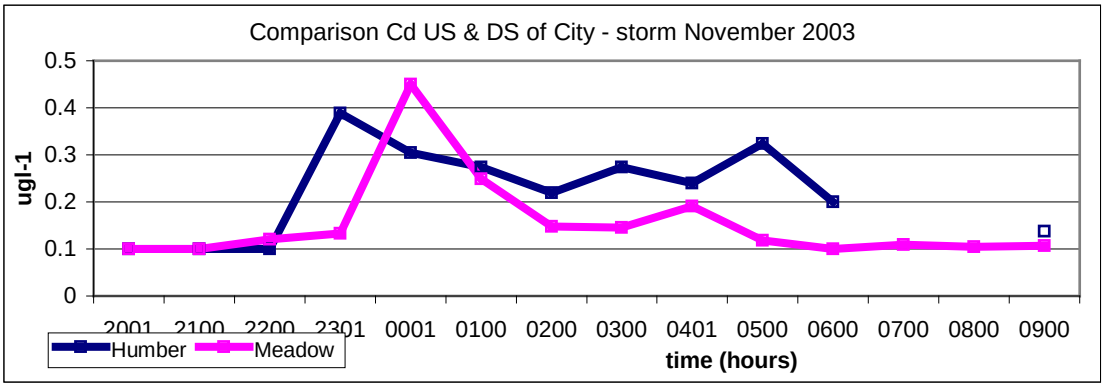
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure k) Sampled Lead comparisons storm event November 2003



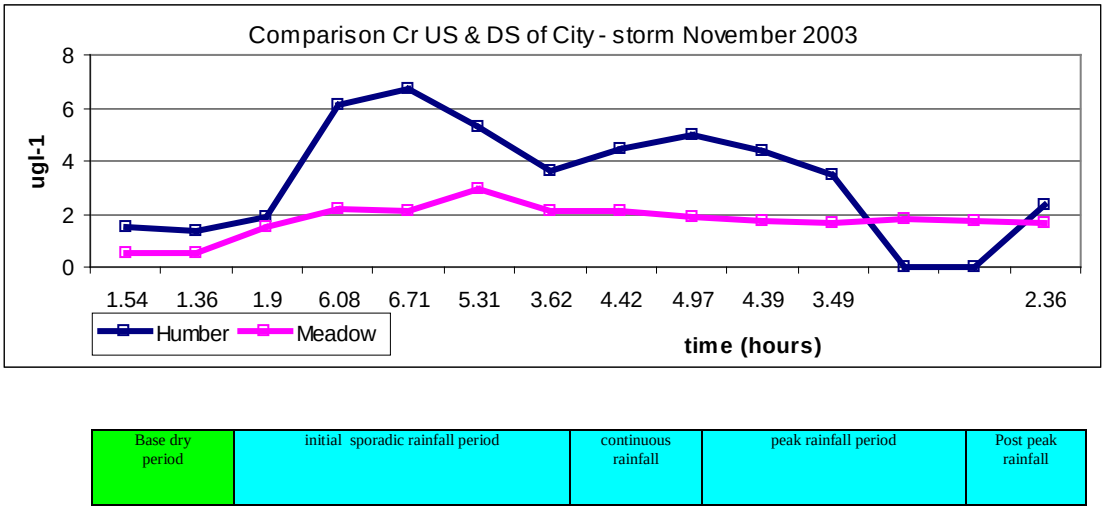
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure l) Sampled Cadmium comparisons storm event November 2003



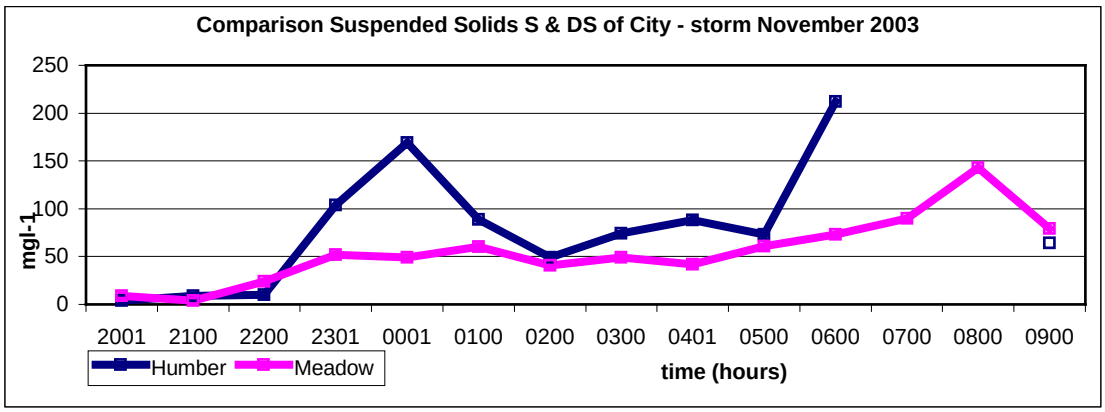
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure m) Sampled Chromium comparisons storm event November 2003



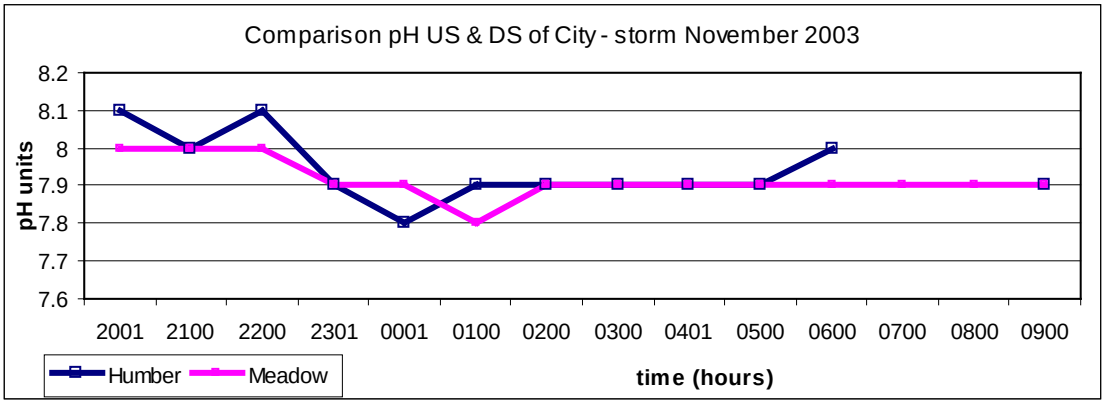
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure n) Sampled S.S. comparisons storm event November 2003



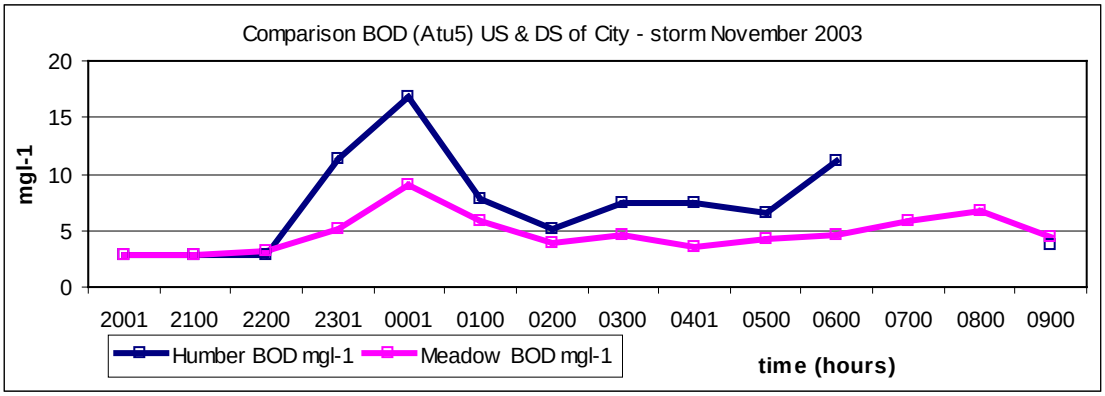
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure o) Sampled pH comparisons storm event November 2003



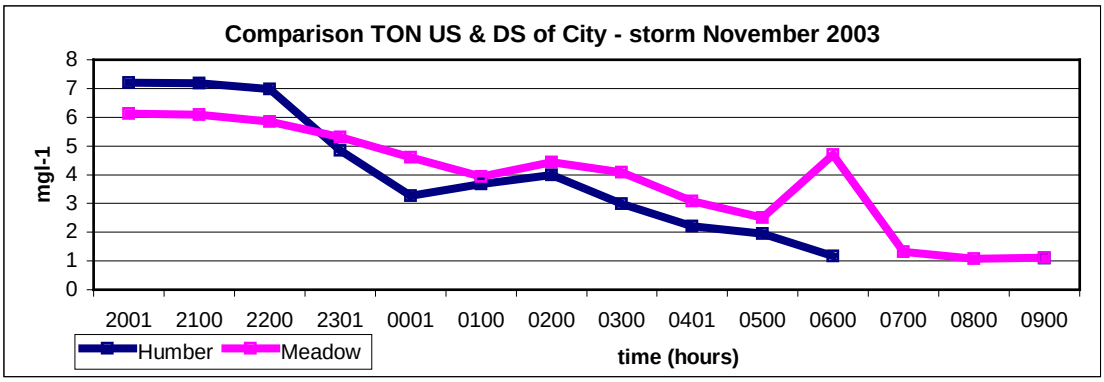
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure p) Sampled BOD comparisons storm event November 2003



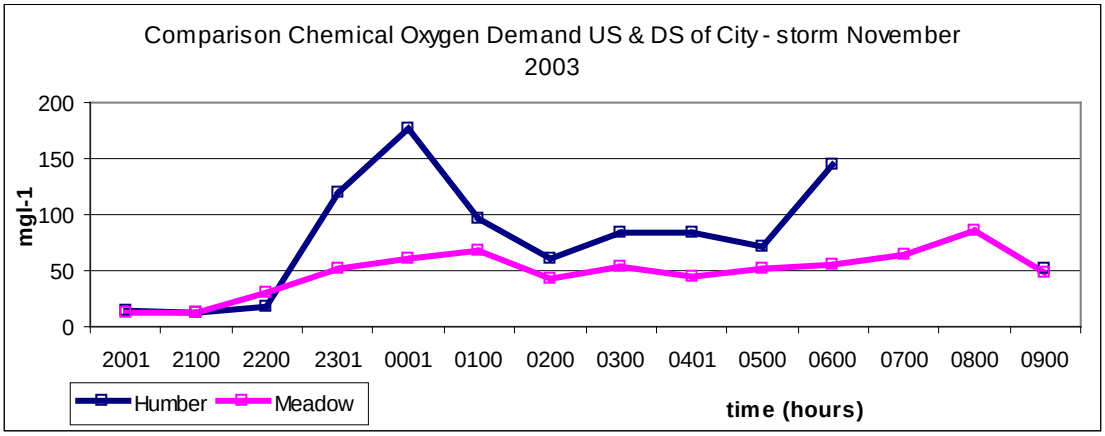
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

Figure q) Sampled TON comparisons storm event November 2003



Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

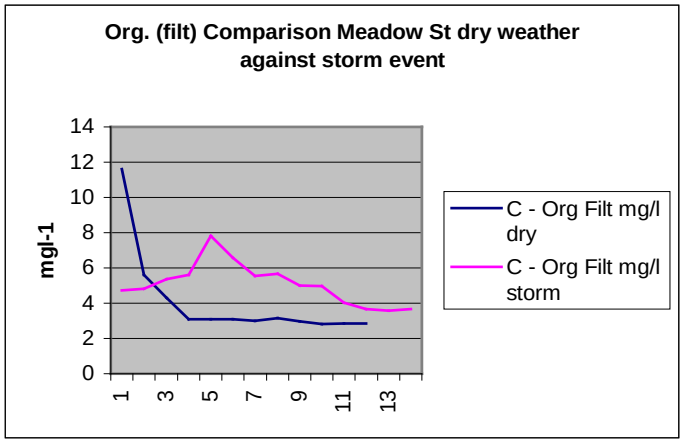
Figure r) Sampled COD comparisons storm event November 2003

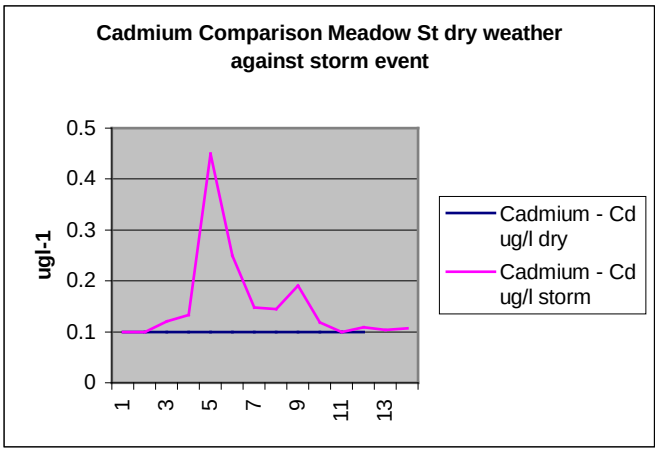


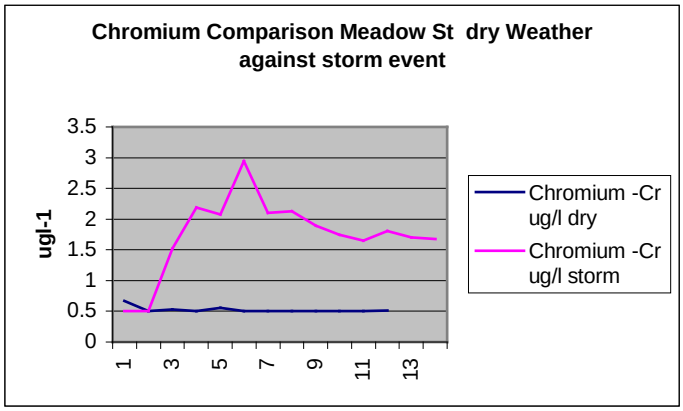
Base dry period	initial sporadic rainfall period	continuous rainfall	peak rainfall period	Post peak rainfall

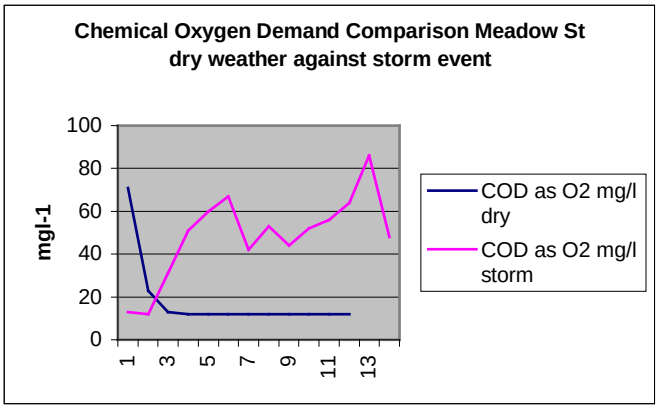
Appendix 10.1

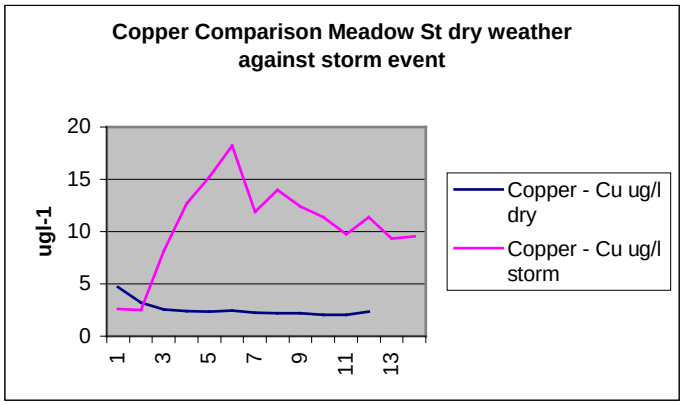
Meadow Street September dry weather against November storm comparison 2003

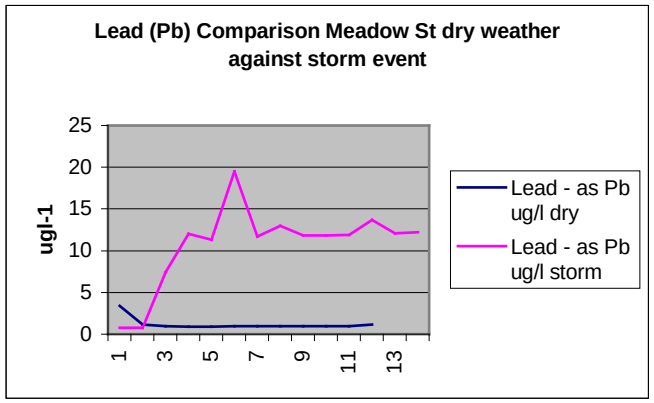


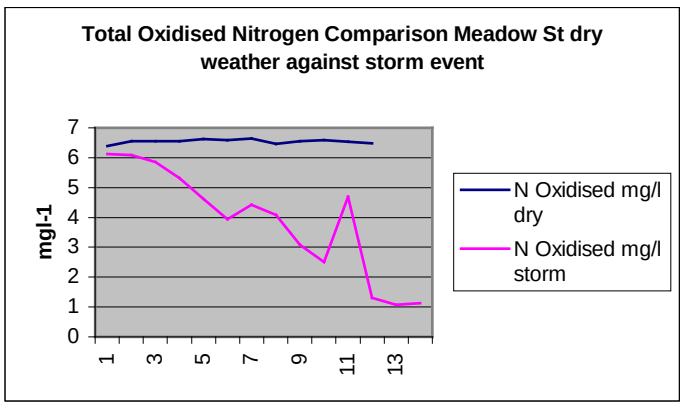


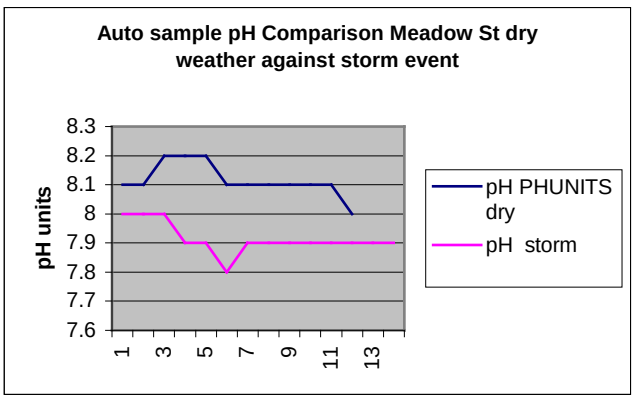




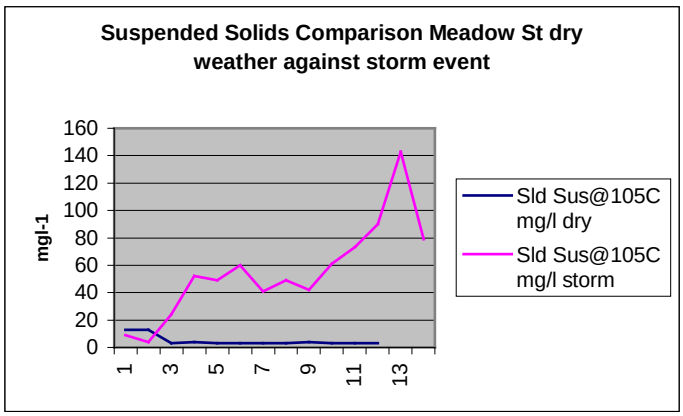


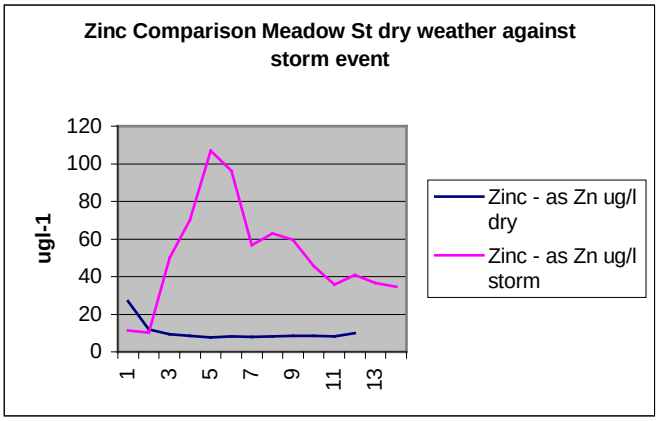


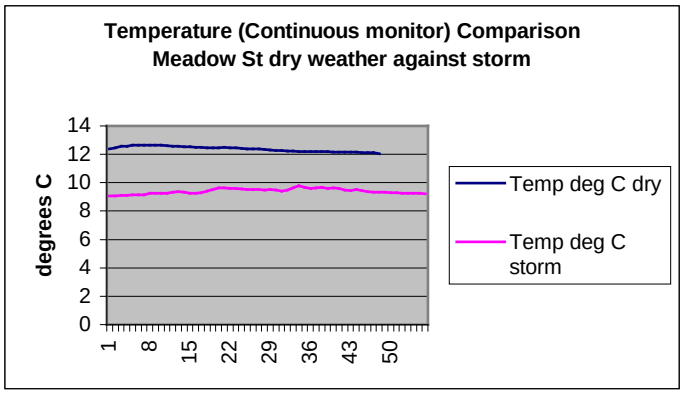


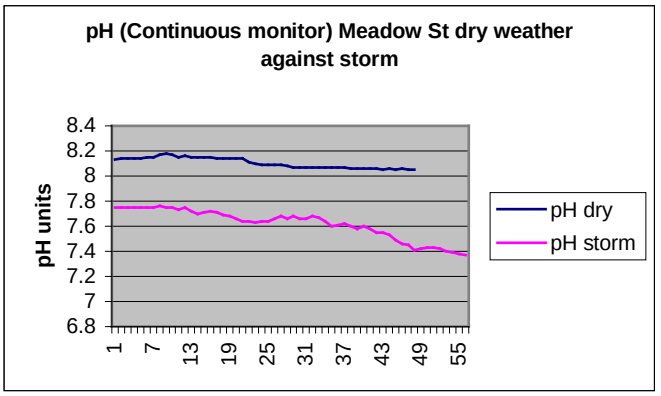


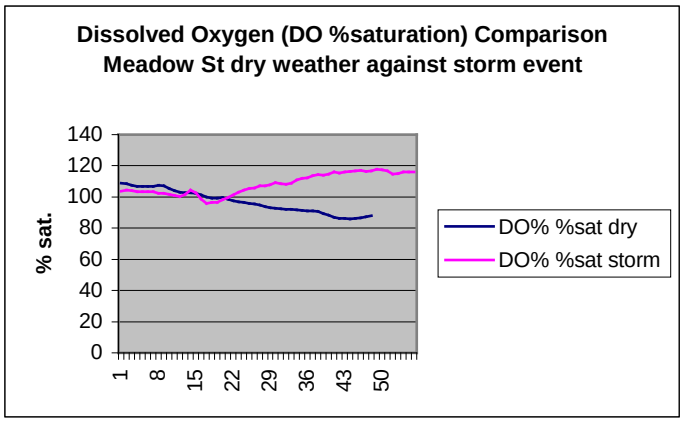
Meadow Street September dry weather investigation against November storm comparison continued

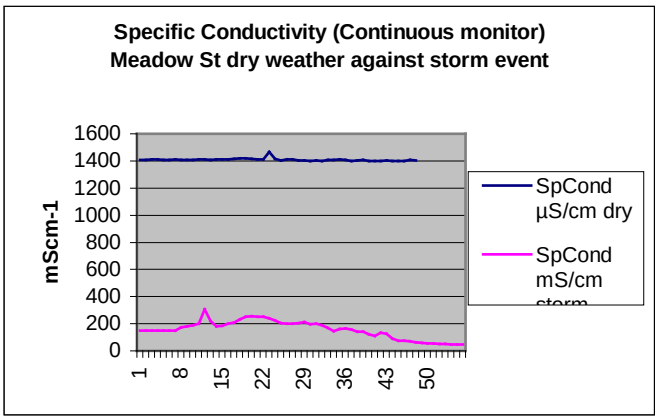


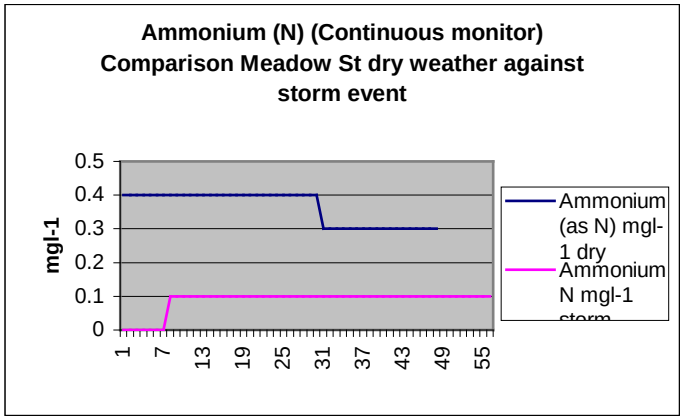




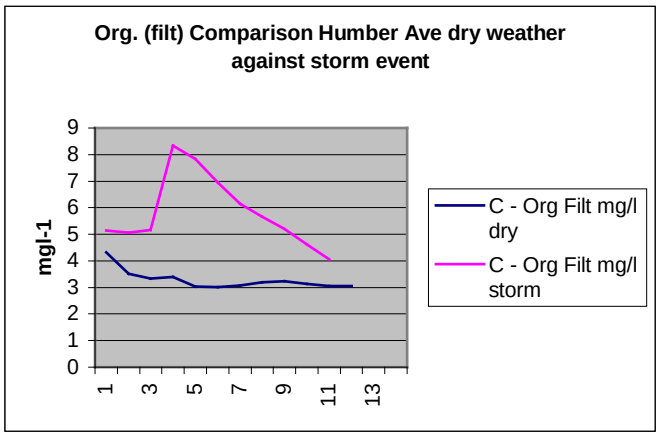


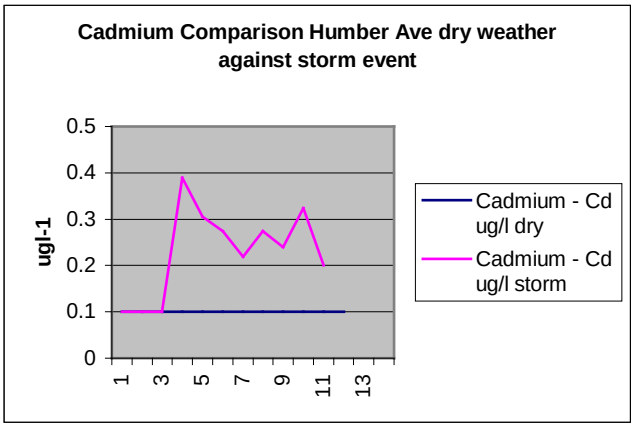


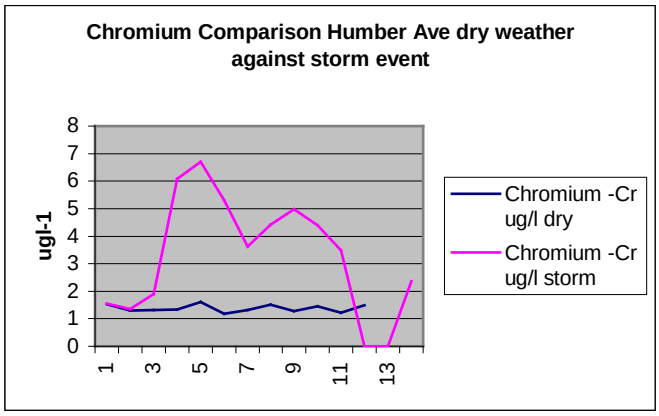


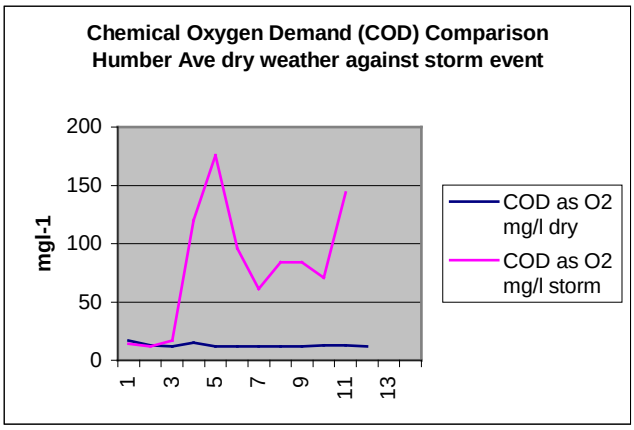


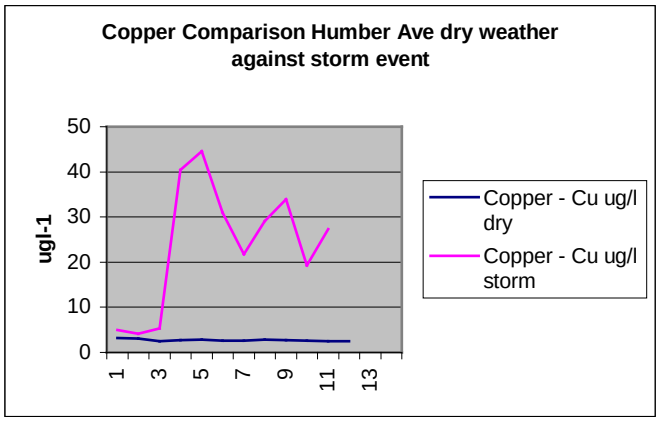
Comparison Humber Avenue September dry weather investigation against November storm 2003

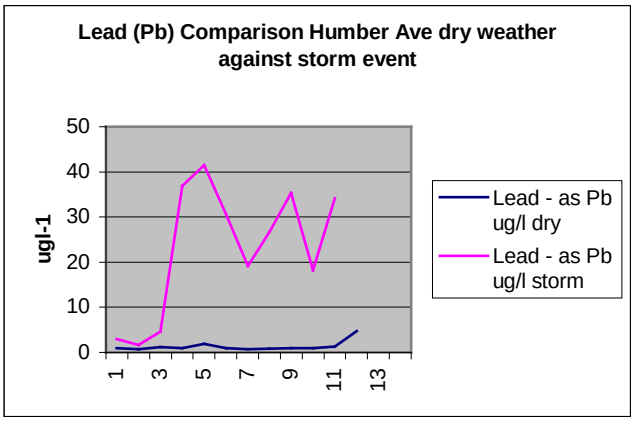


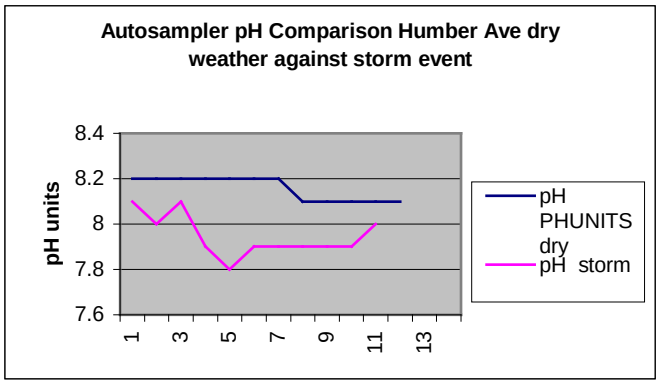


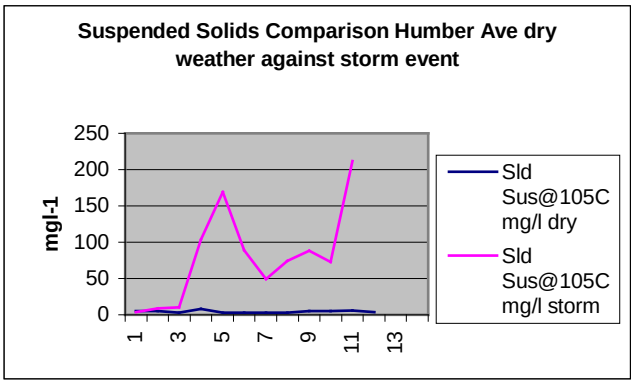


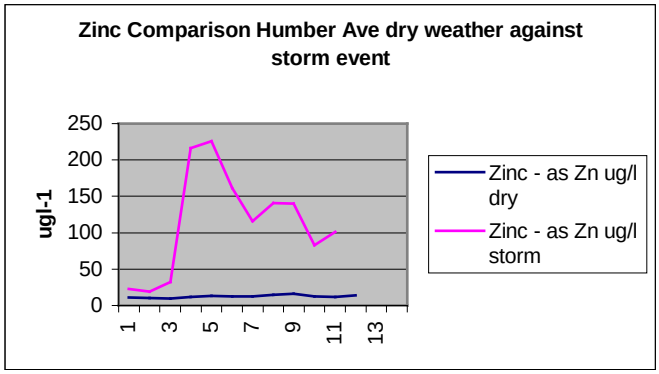












Appendix 11

i) Pre-Calibration Assembly.

- After cleaning the sondes, grease the D.O washer and screw into the unit. Replace the membrane. If there is a build up of deposits on the silver and gold sensors use the sandpaper like discs to remove the deposits. Five wipes either way following the grain should be sufficient. Once the membrane is placed on, make sure there are no air bubbles, if there are, replace the membrane again. Remember to trim all the excess membrane using a knife.
- Grease the washers on the pH probe and then place inside the guard. Grease the guard washer and then screw in to the ISE 1 port. The probe should not be screwed too tightly to prevent cracking.
- In the ISE 2 port screw a blank cap to protect the connections from the solutions.
- Attach a clean probe guard (with the end removed) to the sonde, to enable the probes to calibrate whilst standing upright.
- Do not attach the ammonium probe at this point.

ii) Calibration of pH

Plug the sonde into the computer and open the Ecowatch software. A grey screen appears. Click upon the cursor with the yellow and black sonde on (the sixth box in.) A blue screen will then appear. Type MENU. The choices 1 to 8 appear. Press 8.

The two solutions required are pH 7 and 10. Place the sonde in the pH 10 solution. On the computer the mV readings will be showing under the ISE 1 column. Repeat this for pH 7 and the results that should be attained are as follows:

pH1O = -170 mV ± 50.

pH 7 = O mV ± 50.

If the readings are within calibration limits, press escape. The screen will return to the first menu. To calibrate, press 2, pH is then choice 6 and the calibration will be a two-point calibration. Enter the calibration solution pH value. The sonde must always be calibrated in the pH 7 first, so type in 7.000 and then enter once.

The calibration will take about five minutes; stir the sonde occasionally and once more when it has settled. If it remains settled or fluctuates only slightly after this press enter. The message will then read 'calibration accepted'. Take the sonde out of the pH 7 and rinse it in a pot of deionised water. Place the probes into the pH 10 and type 10.000 and press enter once. Repeat the calibration method as before.

If the probes are reading correctly then the display will return to the probe options. If the calibrations are not accepted the following procedure is followed:

- Clean the probe again especially around the neck area where there are two holes in the glass case.
- Unscrew the probe and check to see if there is any water in the contacts. Clean out using cotton buds and paper towels. Also check for any build up on the connections.
- Change the calibration solutions for fresh ones. This is not usually a problem in the case of pH.
- If the mV readings are now correct this is not usually a problem for continued operation. If they are still wrong, resort to the 600-uncal menu (See 600-uncal menu.)

  Re-hydrate the probe in a pH7 solution.

iii) Specific Conductivity Calibration.

Rinse the probes in water; place in the solution 1.270 mS cm^{-1}. Ensure that the conductivity well is submerged. Press 1 and 1 again for Specific Conductivity.

Enter 1.270 then press enter once.

The figures will then calibrate. When they become stable press enter and it should accept the calibration. If it does not:

- Check the electrical contacts as with the pH probe.
- Clean the electrodes with the brushes to make sure there is no build-up.
- Recalibrate before entering the 600 un-cal menu.

iv) Dissolved Oxygen calibration.

From the specific conductivity calibration menu, enter 0 to return to the main menu. Press 8 to enter the diagnostics menu. The D.O charge should read between 25 and *75.* The usual level being in the fifties. If correct, place in the grey calibration cups with a couple of millimetres of water. Do not push the sonde in because this builds up pressure; place it so there is a seal between the rubber ring and the cup. Leave this for around ten minutes to saturate the air. Press escape to exit diagnostics, press 2 to calibrate, press 2 for D.O. and then press 1 for DO% and then enter 760.000 and again enter, for the calibration to begin. The calibration takes 35 seconds. Once it has finished it should read ‘calibration successful’. Press the ‘enter’ key twice, followed by the zero key twice. Confirm exit. This will then shut the sonde off while the ammonium probe is attached.

If there are problems with the calibration undertake the following:

- Reassemble the probes, wash with de-ionised water, remove any build-up upon the electrodes, replace the membrane.
- Check the diagnostics; if they are within the limits then repeat the calibration procedure again.
- If they are not within limits, enter the 600-uncal menu.
- If this procedure fails, replace the membrane and leave overnight.

v) Ammonium Calibration.

Take the cap out of the ISE 2 port, grease all of the washers on the ammonium probe and guard and screw the probe into the port in a similar way to the pH probe.

Fill two beakers with l mg l^{-1} calibration solution, one with the 100 mg l^{-1} solution and another with deionised water. Place one of the 1 mg l^{-1} beakers back into the fridge to cool (4^0C) and leave the other to reach ambient temperature.

Enter the sonde calibration screen by typing 'menu' and press the enter key. Enter the diagnostics menu (8), place the sonde into the l mg l^{-1} solution and take the mV readings. The same procedure is repeated with the 100 mg l^{-1} calibration solution. The following readings should be obtained:

1 mg l^{-1} = O mV $\pm$ 50.

100 mg l^{-1} = 11O mV $\pm$ 50.

If these readings are correct press Escape to exit, 2 to calibrate, 7 to enter the ammonium menu. The calibration is 3 point so enter 3 and type in 100.000.

Ensure that the 100 mg l^{-1} solution is being used and press enter. Once the figures become stable, (this may take up to 30 minutes with a few gentle stirs), press enter. If this is successful take the probe out of the solution, place in the water to rinse off, then place it into the 1 mg l^{-1} solution. This solution must be over 10 ^{o}C. Repeat the process as with the 100 mg l^{-1}. Once this has settled press enter and if accepted as correct, place into the cold 1 mg l^{-1} solution from the fridge, repeating the process.

Once this is completed press zero twice and confirm 'exit' to shut down the sonde. The calibration is complete. Any problems encountered while calibrating the ammonium (which is more than likely) can be addressed as follows:

If the diagnostics are wrong, or the calibrations are being refused: Change the solution.

It is very important that the 1mg l^{-1} is fresh, and should never be put back into the main bottle, as this will ruin the rest of the solutions. The ammonium levels in the 1mg/i can double over night once it has been used for a calibration.

- If this has not worked then wet a cotton bud in a 100mg/i solution and gently wipe the tip in order to clean the membrane.
- Check the connections inside the well where the probes interface with the unit. Make sure they are not corroded or wet.
- If this fails then place the ammonium tip in a 100 mg l^{-1} solution overnight for it to rehydrate.
- If the probe is still reading wrong after this, especially if it is very jumpy during readings, a new tip may be required. These have to be hydrated for at least 24hours before use. A normal life of a tip is around 3 or 4 months.

vi) The 600-uncal menu – deletion of calibration settings.

Type 600 then press enter, twice. Type ‘menu’. This function allows deletion of calibration attempts, when a sonde is not calibrating properly. Type 2 for the calibrations option and select problematic probe. Use the one-point calibration option. Type ‘uncal’ and then press the enter key.

To exit this menu you must then press Ctrl X and wait until it returns to the normal screen. Then type ‘menu’ as before.